SIXTH ANNUAL REPORT ON CACAO RESEARCH 1936

IMPERIAL MYCOLOGICAL
1937
INSTITUTE

Via colendi haud facilis.

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SIXTH ANNUAL REPORT

ON CACAO RESEARCH 1936

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PLATE I

Fig. 1.

Fig. 2.

Marginal Leaf-scorch of Cacao
($\frac{3}{4}$ natural size)

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A.—BOTANICAL SECTION.

THE BOTANICAL PROGRAMME OF 1936.

By E. E. Cheesman.

The Botanical Report for the year 1936 is necessarily very brief. Earlier Reports, and particularly that of last year, have foreshadowed the situation which has now arisen, in which routine propagation and general consolidation of the knowledge recently acquired must have priority over new researches and occupy most of the time of the staff. Staff reduction has also limited progress, and from September 1935 to June 1936 there was no Cacao Research officer at all, and only the routine necessary to preserve continuity could be handled by the Botanical Department.

Propagation has gone on steadily throughout the year, and the nurseries are now sufficiently established to be drawn upon for material for field experiments in 1937. These experiments are discussed below.

Mr. O. J. Voelcker, seconded from the Department of Agriculture, Nigeria, took up the duties of Cacao Research botanist towards the end of June, and has since given attention to studies of pollen compatibility. The demonstration of widespread self-incompatibility in Trinidad cacao was the most striking result of the preliminary investigations of the past five years into the problems of fruitfulness. Connected as it is with the still imperfectly understood subject of cross fertilization of cacao, it has bearings of the first importance on selection of high-yielding clones, as well as upon studies of yield in seedling cacao. This, therefore, ranks first among the new discoveries which need consolidation and amplification, and is being treated accordingly. It is desirable for Mr. Voelcker's experiments to run at least a full year before final conclusions are drawn from them, especially as earlier findings may need to be modified, but he contributes to this Report a preliminary note which will serve to show their scope.

The apparent occurrence of incompatibility in a large proportion of trees passing the rigid standards of I.C. selections is unexpected, and if confirmed may necessitate some adjustments in our main programme. We do not propose at the present stage to drop all self-incompatible trees from the selection list, although they will not be recommended for commercial planting. They are potentially very high yielders, and may possibly show agricultural behaviour justifying their retention, even if for maximum yield they have to be interplanted with suitable pollinators. On the other hand, it may prove desirable to test them under conditions rather different from those of the statistical comparison hitherto contemplated. A random scattering of small plots, with self-compatible trees intermixed, may be expected to mask the influence of self-incompatibility on yield, and it may be possible to get more useful information from a different lay-out. The exact technique to be adopted can only be determined when we know for certain how many of our 100 selections fall into each of the two classes. For this reason, an account of the field experiments already planned, which was to have been included in this Report, has been withheld for further consideration.

For the 1937 planting, which is of the nature of a preliminary trial, the original plan will be followed, and a statistical comparison of six clones will be laid down, including two that are known to be self-compatible. The layout, a set of six randomized blocks, provides also for comparisons between buddings and cuttings, and between chupon and fan material. Each clone is to be represented by 96 trees (24 fan cuttings, 24 fan buds on seedling stocks, 24 chupon cuttings and 24 chupon buds on seedling stocks) and when the trees come into bearing there should be enough cacao from each clone to permit the preparation of adequate commercial samples.

Subsidiary experiments to compare the seedling progenies of certain selected trees with their vegetative offspring are also due to be planted at the earliest possible date.

SELF INCOMPATIBILITY IN CACAO.

By O. J. Voelcker.

The present paper gives an outline of work which is being undertaken on the incidence of self incompatibility in cacao and on the allied subject of cross fertilization. From data published in previous Cacao Research Reports it is clear that strains of cacao growing in Trinidad may be classed with many temperate fruit trees by reason of an inability to set fruit satisfactorily without cross pollination. The results presented here are somewhat unexpected, and these will require confirmation by the collection of further data before a full discussion can be made. No excuse need be given, however, for a brief description of the practical significance of this work, and the reasons why it is being undertaken.

Self incompatibility in cacao was discovered in Trinidad by Pound (1), and a continuation of his work (2) showed that it was of no rare occurrence. This was substantiated by Marshall (3) who found that seven out of 21 trees growing under normal estate conditions were self incompatible during an eight months' investigation. A suggestion was put forward (4) that under certain conditions a self incompatible tree could change to the self compatible state; but the general conclusion remained that self incompatibility might well be an important factor in limiting final crop yield. Indeed Cheesman and Pound (5) suggested that the scarcity of low bearing trees at Aburi in the Gold Coast might be due to the absence of the incompatibility factor. This view has been greatly strengthened by Voelcker's (6, 7) work in Nigeria. Voelcker, in pollination studies and in selection routine, had no difficulty in obtaining self fertilized pods from the West African type of cacao.

If the suggestion were correct that a tree could be self incompatible during part of the year but become self compatible for periods during which the crop was set, then this conditional self incompatibility might well be of little practical importance, provided the periods of setting were long enough to ensure the foundation for a full crop. So important did this change of state appear that it was decided to do a number of hand selfings at regular intervals to find out more about it. Imperial College Selection trees, some of which were thought to demonstrate this change (4), were chosen at River Estate, and hand selfings on these were commenced in July 1936 with the additional object of obtaining self fertilized seed for experimental purposes. Pound's (8) method of controlling pollination was used throughout and was found far more simple than that of Voelcker (9). Only buds which could be reached from ground level were covered, and this accounts for the small number of flowers pollinated on several trees, though during certain periods some of the trees flowered only very sparingly. After selfing by hand the flowers were again covered till the third or fourth day, when the glass tubes were removed and tags substituted. A record was kept of the length of time between pollination and shedding for each flower.

It is here necessary to consider the term " set " used by writers on cacao pollination. An unpollinated flower is shed on the first, second or third day after opening, (Stahel (10), Jones (11), Voelcker (6)), except for rare examples where the whole petiole and flower withers. It may confidently be assumed that flowers which remain after the third day do so as a result of pollination. Hand pollinations on a tree may give a high percentage " set " at six days, but none " set " at ten days. In practice, when judging whether a tree is self compatible or self incompatible it is advisable to consider as " set " only those fruits which reach what is generally recognized as the cherelle stage. In Table I, 14 days have been used as the interval to decide whether a self pollinated flower not only may become fertilized but also has sufficient vigour eventually to reach maturity should other factors permit. It must clearly be understood that this interval of 14 days has only been adopted as a matter of convenience, but it is thought to give a truer picture of self incompatibility than the six day interval used by Pound (1), or the seven day interval employed by Marshall (3). Further reference will be made to the initial growth observed in fruits which never reach the cherelle stage when fuller data shall have been obtained.

An inspection of Table I brings to light or substantiates the following points:—

1. The trees examined may be divided for all practical purposes into those which are self compatible and those which are self incompatible, though it should be noted that certain trees classed as self incompatible do occasionally produce cherelles as a result of self pollination.

2. During the period to which the table refers there appears to be no change from self incompatibility to self compatibility or *vice versa*. The incompatible trees which do occasionally produce cherelles on selfing seem to do so irrespective of the dates under consideration.

3. The number of self incompatible trees is unexpectedly large.

4. The proportion of fruit remaining after 14 days on the self compatible trees to the number of flowers self pollinated is similar to the Nigerian figure.

During the period under consideration the self incompatible trees have been setting fruit freely. Indeed, the yield from these trees over the last few years has been so good that they passed the very high standard set for the Imperial College Selections. The assumption is made that all the pods on these self incompatible trees are the result of cross pollination, and that the removal

Table I.

SELF POLLINATIONS—JULY, 1936 TO JANUARY, 1937.

Tree.	17.7.36 to 30.8.36		15.9.36 to 26.9.36		14.10.36 to 25.10.36		10.11.36 to 21.11.36		8.12.36 to 19.12.36		5.1.37 to 9.1.37		TOTAL.	
	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.	Number pollinated.	On after 14 days.
I.C.S. 100	20	1	16	1	12	0	4	0	3	0	—	—	55	2
I.C.S. 2	81	0	17	0	18	0	25	0	13	0	4	0	158	0
I.C.S. 1	26	12	3	1	4	2	2	2	—	—	—	—	35	17
I.C.S. 99	—	—	—	—	3	0	4	0	1	0	2	0	10	0
I.C.S. 90	2	0	—	—	5	0	8	0	6	0	—	—	21	0
I.C.S. 86	14	1	10	0	7	1	6	1	5	0	—	—	42	3
I.C.S. 6	17	12	—	—	2	2	1	0	3	3	1	0	24	17
I.C.S. 7	22	14	—	—	5	2	4	3	3	3	1	0	35	22
I.C.S. 9	22	14	2	1	—	—	—	—	—	—	—	—	24	15
I.C.S. 3	27	1	2	0	8	0	4	0	7	0	2	0	50	1
I.C.S. 83	17	1	43	1	31	3	23	0	—	—	—	—	114	5
I.C.S. 20	18	0	21	0	17	0	16	0	4	0	—	—	76	0
I.C.S. 97	103	0	57	0	44	0	20	0	17	0	9	0	250	0
I.C.S. 4	62	0	36	0	7	0	1	0	5	0	—	—	111	0
I.C.S. 94	5	0	4	0	—	—	—	—	—	—	—	—	9	0
I.C.S. 5	107	0	54	0	63	0	41	0	41	0	12	0	318	0
I.C.S. 17	86	1	21	0	26	1	15	0	9	0	4	0	161	2
V 14	45	31	20	12	26	20	20	13	5	4	1	1	117	81
360	67	0	35	1	43	0	57	0	37	0	14	0	253	1
Nigeria. Six West African type cacao trees, self pollinations over one year 24.3.31 to 23.3.32													532	327

Controls.—St. Augustine trees unpollinated. 280 flowers unpollinated, 276 fallen by 3rd day. Two flowers wilted, two flowers reached cherelle stage, but ants found in the bottle.

of the surrounding trees would result in failure to set any crop at all. The assumption presupposes a carrying agent of pollen from one tree to another, and such an agent is not at the moment definitely known. So important do these conclusions appear that additional proof is being sought to show that the pods on these trees found to be self incompatible by hand selfing are the result of cross pollination. An indication can be obtained by studying the inheritance of axil spot (Harland (12)) and bean colour (Wellensiek (13)). Hence a large number of beans have been examined, pod by pod, and then germinated. The results are not yet complete but have given no contradiction to the assumption postulated.

Further hand selfings and controlled crosses are to be made during 1937.

Discussion.

Reference has been made to the similarity of percentages of fruit remaining after 14 days from pollination between the Nigerian trees and the

self compatible River Estate trees examined. This invites a fuller consideration of the possible depressing influence on yield per acre that a high proportion of self incompatible trees may have. The high yields obtained in West Africa compared with those in Trinidad have been the subject of much comment, and a variety of causes have been postulated. Shephard (14) has shown the undoubted importance of the age factor, but the average yield figures he gives for fields less than 25 years old (366 lb. per acre) compare unfavourably with the published yields in Nigeria (Owena 963 lb. per acre, Ajia 900 lb. per acre, Moor Plantation 800 lb. per acre) (7) and in the Gold Coast (average from experiment stations 814 lb. per acre, Dade 1,200 lb. per acre (15, 16)). The fact that most of the I.C.S. trees yield at the rate of over 2,240 lb. per acre, and cover a wide range of soil and climate, seems to disprove the suggestion that Trinidad soils and climate are much inferior to those of West Africa. Few would be willing to believe that the methods of growing cacao on the West Coast are so greatly superior to estate practice in Trinidad.

The conclusion is thought justified that there are factors inherent in many of the Trinidad trees limiting yield, and that these factors are partially or totally absent in the West African population. For an individual tree the yield is determined by any of the following :—

Number of flowers produced.
Number of flowers fertilized.
Number of cherelles or immature fruit lost.

Observation suggests that it is of very rare occurrence for the number of flowers produced to be the limiting factor in final yield. With regard to loss of cherelles, Pyke's (17) remarks may be quoted : " Individual trees vary greatly in their liability to cherelle wilting, so much so that a general graph for a plot as a whole is of limited use in considering this statistic . . . . On the River Estate plot the ratio of pods wilted to pods set ranges from 92.5 per cent. to 19 per cent. with a mean of 69 per cent. There appears to be no very close connection between this percentage wilting and the final crop of the individual tree ". The Gold Coast figures (18) are similar, *i.e.* 22 per cent. to 84 per cent. There is, therefore, good reason to investigate more fully the incidence of fertilization as one possible explanation of the difference in yield per acre between the two regions.

The data so far obtained from hand selfings on the 17 high yielding I.C.S. trees show that only four of these are self compatible, and it would be reasonable to assume from this that self incompatibility is of no importance in determining final yield. But the performance of a self incompatible tree will be influenced by neighbouring trees and will vary according to the efficiency of pollen transference and the power of such pollen to cause fertilization. If these 13 incompatible trees had been surrounded by neighbours whose pollen could not cause fertilization, it would be expected that they would have ranked with so many other Trinidad trees as very poor yielders. A realization of this possibility is of particular importance in planting up clonal fields of cacao.

Again, the assumption that perhaps all the pods on these 13 trees are the result of cross pollination, assures the probability that a very mixed progeny will be obtained if such trees are used as parents. If the incompatibility noted in cacao is determined by genetic factors, then there is also little hope of reducing its incidence as long as self incompatible parent trees are used.

But apart from the influence on final yield that fertilization exerts, there is the important fact that cacao is one of the few crops which exhibits xenia in the commercial product. The cacao bean is composed of two cotyledons, and the characteristics of these are determined by the male as well as the female parent. For any particular tree the female parent is of course the same for all the beans produced, but the male parentage may alter depending from which tree the fertilizing pollen came. This has been recognized in Java by Wellensiek (13) who was able to account for differences in bean colour from pod to pod on the same tree. Voelcker (19) working with kola obtained similar results. A Criollo tree self fertilized, or crossed with pollen from other Criollo trees will give white beans, but if crossed with pollen from a Forastero tree will give purple. It is within the common knowledge of cacao planters that certain trees can generally be relied on to yield light coloured beans, but from any one pod the beans may all be dark purple. The point may be stressed by contrasting cacao with fruit trees. The characteristics of a Cox's Orange pippin remain substantially the same irrespective of the variety of apple which produced the fertilizing pollen ; in cacao it is the pod which remains the same for any particular tree but the beans that alter in certain characteristics according to the pollen used for fertilization.

Thus further investigation into self incompatibility and natural cross pollination has an important bearing on quality and may have a far reaching effect on yield.

Acknowledgments.

The writer wishes to acknowledge the great assistance afforded him by the Department of Agriculture, and in particular the help given by the Manager, River Estate, whose practical experience has always been at the writer's disposal. Professor Cheesman has given much helpful advice which is here gratefully acknowledged.

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(B) CHEMICAL AND ECOLOGICAL SECTION.

THE CHEMICAL PROGRAMME OF 1936.

By F. Hardy.

The work of the Chemical and Ecological Section for the year 1936, has mainly concerned the biochemistry of cacao. The present report contains five articles describing preliminary biochemical investigations initiated by Mr. J. A. McDonald, Chemist for Cacao Research. This officer resigned his post at the end of the year, and his duties were assumed in October, 1936, by Dr. D. W. Duthie, Lecturer in Chemistry of the College. In consequence of these changes in staff and in the trend of the chemical work, less attention has been devoted to ecology, and our studies of environmental factors in the field have solely comprised an extension of the soil investigations.

Soil Surveys.

As a direct outcome of our earlier ecological soil studies and of manurial experiments based upon their findings, a systematic soil survey of Trinidad was initiated in May, 1936, when Dr. E. M. Chenery, specially appointed by Government, commenced his duties in Trinidad. Prior to that date, the results of a detailed reconnaissance soil survey of the Montserrat District had been published by Mr. McDonald. Three other cacao-growing areas in the Colony, as well as parts of Grenada, had also previously been investigated by the profile method, and the results published, but no detailed soil mapping had been attempted. These additional areas of the Colony comprised (1) parts of Tobago, (2) the Rio Claro District, and (3) the Siparia-Penal-Moruga District, South-Central Trinidad. During June and July, 1936, Dr. Chenery, working in co-operation with Dr. Pound and three other officers of the Trinidad Department of Agriculture, completed a detailed soil survey of the Rio Claro-Tableland-Princes Town District, and prepared an accurate soil map of the area. This map and a descriptive account of the soil-types are now being prepared for publication. Subsequently, Dr. Chenery commenced a detailed soil survey of the Sangre Grande-Manzanilla District of Eastern Trinidad. Certain other small areas, notably the Toco District and parts of the Cedros, Erin and Guapo Districts of Southern Trinidad, as well as some Northern Range Valleys, have been investigated by the profile method, and brief typescript reports have been compiled on their main soil features. In the prosecution of these investigations, considerable help has been afforded by special petrographical maps prepared for our use by the geological departments of certain oil companies operating in Trinidad. Through this aid, the field mapping has been greatly expedited, but it will still be necessary to explore the soils by means of the auger, and to examine their characters by shallow and deep profile pit sampling, supported by routine physical and chemical laboratory analyses of representative soils samples. At the same time, comparisons will be made between cacao soil-types and forest soil-types derived from the same parent rock materials. The investigation of the *forest soils* of Trinidad indeed forms an integral part of the survey, since increasing demands for new lands for cacao planting, for peasant settlement, and for exploitation for oil, urgently necessitate the acquisition of detailed knowledge of their agricultural possibilities. Such information is constantly being sought by the Sub-Intendant of Crown Lands, the Department of Agriculture, and the Forest Department. Evidently the soil survey is one of the most urgent needs of the Colony during its present phase of transition from land utilisation to scientific agriculture and sylviculture.

Leaf-Scorch of Cacao.

A conspicuous symptom of unsuitable cacao environments, particularly with regard to deficiency of available soil potash, has been discovered by means of sand culture experiments and detailed soil surveys. The symptom may be described as a marginal leaf-scorch, and cacao leaves prone to scorching, or already showing the symptom, reveals characteristic chemical composition as determined by ash analysis. Investigations of leaf-scorch are described in a special article forming part of this report.

Manurial Experiments.

Subsequent to the inauguration of the Cacao Research Scheme, seven large-scale field manurial experiments on cacao based on the Latin Square plan, have been laid down by the Officer of the Chemical Section (Mr. J. A. McDonald). These experiments and a few others then in being, were handed over in January, 1936, to the Department of Agriculture. They have since been widely extended by Dr. F. J. Pound. Other simple types of manurial and cultivation experiments have been added during the past year. An account of these experiments, and a discussion of the results obtained up to the end of 1936, form a part of this Annual Report. Thus the prosecution, not only of the detailed soil survey of cacao lands, but also of field experiments designed to test the manurial requirements of different soil-types, are now directly under the charge of the Department of Agriculture, officers of the College acting merely in an advisory capacity. The routine laboratory examination of soil samples concerned in this work is nevertheless still being

undertaken at the College, and the compilation of reports based on its results is still a charge on the Chemical Section of Cacao Research.

West African Cacao Soils.

A new departure in the investigation of cacao soils was initiated during 1936, when some 190 soil samples, taken from 19 profile pits representative of cacao-growing lands of the Gold Coast, were examined at the College. This work is outcome of the co-operation afforded by Mr. M. Greenwood, Agricultural Chemist of the Gold Coast Department of Agriculture, and formerly a Post Graduate Student at the College. An account of some Gold Coast cacao soils forms the first article of the present report. An attempt is made therein to compare the main geological, physical and chemical features of these West African cacao soils with those of some West Indian cacao soil-types. It is hoped to extend the comparisons to other West African cacao soils, including types occurring in Nigeria.

Cacao Biochemistry.

Little is known of the biochemical factors which control " quality " in raw cacao, in-so-far as the development of colour, flavour and aroma of the roasted product is concerned, but it is believed that a laboratory study of the subject from four main aspects may help to elucidate the meaning of the term. The four aspects deserving investigation are (1) the possible differences in chemical composition between well-known varieties of cacao, such as Criollo, Forastero and Calabacillo, (2) the effect of ripening on biochemical composition, (3) the effect of environmental growth factors, such as climate, soil-type and manurial treatment, (4) the effect of fermentation and drying.

The rôle of tannin-like substances and theobromine in controlling taste and flavour is frequently stressed in cacao literature, and consequently chief consideration has been given to methods for estimating tannins and theobromine in raw cacao, and the application of these methods to the problem of " quality ". Unfortunately, the preliminary investigations proved disappointing because truly representative material in sufficient quantity was not available when the investigations were begun. The preliminary results show that the tannin and theobromine contents of the raw bean may vary considerably, depending on type of cacao and degree of ripeness, but the variations were not regular, so that no definite conclusions as to their significance can yet be established.

In the case of fermentation, however, marked differences were revealed between unfermented and fully-fermented beans. Contrary to previously-published results, tannin was found to *increase* in the kernel during fermentation, while theobromine, in accordance with previous results recorded by Wadsworth, was found to *decrease* considerably in the kernel, and to increase proportionately in the shell. Differences were also found in the theobromine content of the kernel and shell of different varieties of cacao. It is consequently suggested that theobromine, rather than tannin, may be the chief factor concerned in the loss of bitterness during fermentation, and in the harsh taste of " low quality " cacao.

The identity of the " tannin complex " of raw cacao is difficult to establish; the term may include various more-or-less definite substances, each of which may play a particular part in deciding taste and flavour. The identification and quantitative estimation of these different tannin components should be investigated in greater detail, and the contribution of each to " quality " should be specifically studied.

The fat content of raw cacao is an important consideration to the manufacturer. The preliminary determinations of fat content, which formed a part of the biochemical work, show that its amount does not reach a maximum until the bean is fully ripe. Not much difference was found between the fat contents of different varieties of cacao, nor was its gross amount found to alter appreciably during fermentation. No attempt has yet been made to fractionate the fat component of cacao beans, although it is fully realised that the importance of the unsaponifiable component of cacao fat may be considerable, particularly with regard to the behaviour of cacao during manufacture into chocolate.

While it is evident that biochemical problems concerned in the definition of " quality " of cacao are extremely complex and difficult, it is hoped that further work along the lines indicated, and with the obvious facilities afforded by the accessibility in Trinidad of fresh material for laboratory examination, may eventually elucidate some of the main facts. The possible future co-operation in this work of cacao chemists concerned in the actual manufacture of chocolate and cocoa overseas, may later be sought, since it would be impossible fully to define " quality " without reference to the changes that may ensue during roasting and drastic mechanical treatment.

PART I.—CACAO SOIL INVESTIGATIONS.

(1) SOME GOLD COAST CACAO SOILS.

By F. Hardy and G. Rodriguez (*Analyst*).

(I) Introductory.

In accordance with arrangements made with Mr. M. Greenwood, Agricultural Chemist of the Gold Coast Department of Agriculture, serial soil samples, 190 in number, were procured during May, 1936, from 19 profiles representative of cacao soil-types occurring in the Eastern and the Central Provinces of the Gold Coast Colony and Ashanti. These samples were air-dried and sifted, and their contents of gravel determined. They were then shipped to Trinidad for laboratory examination by the routine methods employed in the Soils Department of the College. The full data are not presented in this article, but the results for the surface six-inch soil layer, (which is believed to furnish the main supply of nutrients to the cacao tree) are set out in a table. An attempt has also been made to assess the nutrient status of the soil at each profile site by applying an arbitrary scale of marking to the physical and chemical laboratory data. For purposes of comparison, marks were also assigned to well-known cacao soil-types occurring in Trinidad, Tobago and Grenada, for which a considerable amount of information has been accumulated during our investigations of cacao soils. The soils are arranged in the table in their approximate order of fertility, as gauged by this computation. Consideration of yield data in relation to fertility status, based on the laboratory analyses, is deferred until further soil profile samples have been examined at a future date.

(II) Petrographical Description of the Parent Rocks.

The Gold Coast country consists of metamorphic and igneous rocks of various kinds, and of sedimentary rocks, including calcareous types.

The *Metamorphic Rocks* are mainly Pre-Cambrian in age, comprising the Lower and Upper Birrimian Series, but some are Pre-Middle Devonian, comprising the Akwapimian Series. The original rocks were both sedimentary (ranging from shale to grit, conglomerate, and limestone) and igneous, including lavas and volcanic tuffs. These rocks have been greatly altered, contorted and sheared by intense earth pressures, and are now represented by slate, schist, gneiss, quartzite, greenstone and marble.

The *Igneous Rocks* are mainly intrusive. They chiefly comprise an older Cape Coast Granite Series, and a newer series of hornblende granite (Dixcove Granite), as well as basic types. They occupy a large part of the Gold Coast Colony, Ashanti and the Northern Territories.

The *Sedimentary Rocks* are Pre-Cambrian, Pre-Middle Devonian, Devonian, Carboniferous and Cretaceous in age. They comprise several geological systems, including the Voltaian Series. They are represented by a wide range of mechanical types, as well as limestones and calcareous sandstones. The bedding is usually horizontal, and frequently the newer strata conformably overlie the older metamorphic rocks.

Rock weathering has been very profound under the humid climatic conditions that obtain in the Gold Coast, and has proceeded over long periods of time, so that the soil profiles are generally fully mature and very deep, the unaltered parent rocks seldom being exposed in the 6-foot pits dug for the purpose of soil examination and sampling. Occasionally rotten rock appeared in the deep profile, but the exact nature of the original rock could not easily be determined, not even by mineral separation in heavy liquids, which was attempted. Nevertheless, the petrological type of parent rock was approximately identified by the positions of the profile sites as plotted on a recent geological map of the Gold Coast. Mineralogical examination verified the location in most cases.

The chief mineral occurring in the soils is quartz; all the soil types are distinctly sandy, quartz sand (2.0 to 0.04 mm. grain size) mainly ranging in amount from about 40 to 90 per cent., and Index of Texture values from 0 to 20, rarely above. Sand contents and Index of Texture values tend to diminish down the profile. In addition, white mica is plentiful in the soils derived from Cape Coast Granite, and the single example (alluvial soil) derived from Dixcove Granite contains conspicuous fresh hornblende crystals.

Many of the sedentary soils are very gravelly, but alluvial types could be distinguished by the paucity of gravel in them. The gravel is mainly quartz, but some soils also contain hard ironstone concretions or pieces of laterite.

(III) Classification of the Soil Types.

Based on the field descriptions of the soil profiles and the results of the laboratory examination of the samples, the Gold Coast soils may tentatively be classified into the following types :—

(A) Red Earth.

(I) Sedentary.

(1) Derived from *Voltaian* sedimentary rocks, probably including calcareous rocks.
Profiles Nos. 13 (Bukrum) ; 14 (Sesiamang) ; 15 (Samang) ; 18 (Kwabea).

(2) Derived from *Akwapimian* and *Lower Berrimian* metamorphic sedimentary rocks.
Profiles Nos. 1 (Aburi) ; 5 (Kumasi).

(II) Alluvial.

(1) Derived from *Akwapimian* metamorphic rocks.

Profile No. 17 (Cherechum).

(B) Yellow Earths.

(I) Sedentary.

(1) Derived from *Cape Coast Granite.*

Profiles Nos. 3 (Efiduasi 2); 7 (Asuansi 1); 8 (Asuansi 2); 19 (Amoyu).

(2) Derived from *Upper Birrimian* metamorphic basic igneous rock (Greenstone).

Profiles Nos. 11 (Nkawkaw 1); 12 (Nkawkaw 2).

(3) Derived from *Lower Birrimian* metamorphic sedimentary rocks.

Profiles Nos. 6 (Mbeim); 10 (Manhyia).

(II) Alluvial.

(1) Derived from *Cape Coast Granite.*

Profile No. 2 (Efiduasi 1).

(2) Derived from *Dixcove Hornblende Granite.*

Profile No. 9 (Nkawe).

(3) Derived from *Undifferentiated Granite.*

Profile No. 4 (Dotum).

(4) Derived from *Akwapimian* metamorphic rocks.

Profile No. 16 (Okrakwajo).

The differentiation into Red Earths and Yellow Earths is based chiefly on colour; no complete chemical soil analyses have yet been made with a view to determining "degree of laterisation"; the relationships of the Gold Coast soils to the world groups have thus not yet been elucidated.

(IV) Description of the Soil-Types.

The following brief notes are abstracted from the full typescript report. They present a general view of the six main soil-types that have provisionally been differentiated among the Gold Coast cacao soils so far examined.

(1) *Voltaian Red Earth Soil*: Profiles Nos. 13, 14, 15, 18.

This soil-type apparently includes the best cacao soils of the series. Its most striking feature is the richness of the highly humic surface soil, which is alkaline in reaction (being slightly calcareous), and well provided with mineral plant nutrients and nitrogen. The profile below is very uniform and bright red in colour. Evidently the soil has been derived, at least in part, from some sort of calcareous sedimentary rock, or has been contaminated by limestone residues or hill-wash. The characteristic presence of notable amounts of manganese oxide in the surface soil supports this supposition.

The *surface soil* (0-6 ins.)—*see* table—is a red-brown, alkaline, lime-saturated loamy-sand, containing traces of free calcium carbonate and manganese oxide. Its organic matter content is fairly high (3 per cent.), with high carbon-nitrogen ratio (10.5). Nutrient contents are high, available phosphate ranging 26 to 71 p.p.m. (medium-low to high), and available potash from 76 to 268 p.p.m. (medium to high). The *sub-surface* soil (6-12 ins.) is similar to the layer above, except that it is less alkaline or slightly acidic, and contains only about one-third as much organic matter, of lower C/N ratio (10.0). Its content of available nutrients is less than half that of the top soil. The *subsoil* (one to five ft.) is uniformly bright red in colour. Gravel and ironstone concretions are typically *absent.* Clay content and degree of acidity increase with depth. Organic matter diminishes to 0.4 per cent. at the 4-foot depth, with decreasing C/N ratio. Nutrient status is very low.

Rotten rock may appear at the 4 or 5-foot depth, but the nature of the parent material cannot be determined. The lower layers are patchy in appearance and red and yellow in colour; granular minerals other than quartz are sparse or absent.

(2) *Metamorphic Red Earth Soil*: Profiles Nos. 1 and 5.

This is similar in appearance to the red soil already described but it differs from them in the magnitudes of the different soil factors. Thus, Profile No. 1 (Aburi) (the best of the 19 soils) shows very high contents of available phosphate and potash (over 320 p.p.m. each), and of organic matter (five per cent.) in the surface 6-inch layer, probably because it has been manured. Humus penetration is deep (4 feet), and C/N ratio is high throughout (14 to 9), whilst reaction is uniformly nearly neutral (pH 6.8) even down to the 5-foot depth.

Profile No. 5 (Kumasi; Cadbury Hall) is inferior to the other red earth soils in nutrient status, and is much more acidic throughout the profile (pH 5.4).

(3) *Alluvial Red Earth Soil*: Profile No. 17.

This resembles closely the Voltaian sedentary type, but its nutrient status is inferior. The *surface layer* is slightly alkaline in reaction, and contains appreciable amounts of manganese oxide (0.10 per cent.). The *subsoil* is highly acidic (pH 4.9), and its nutrient status is very low.

(4) *Granite Yellow Earth Soil*: Profiles Nos. 3, 7, 8, 19.

The soil profile of this type displays brown, yellow and grey colours, although red mottling may appear in the subsoil.

The *surface soil* (0-6 ins.)—*see* table—is a dark brown micaceous sand, sometimes gravelly, and appreciably acidic in reaction (pH 6.0). The surface soil is only about 60 per cent. saturated by exchangeable lime, and would need about one ton of ground limestone per acre to correct its acidity. Organic matter content ranges from one to four per cent.,

with high C/N ratio (11.0). Nutrients vary in amount; in two of the profiles (Nos. 19 and 7) they are abundant (over 100 p.p.m. for phosphate and potash), whilst in the other two (Nos. 3 and 8), they are low in amount (20 and 50 p.p.m.), and inadequate for productive cacao soil. The *subsurface* soil (6-12 ins.) is a gritty or gravelly, yellow, micaceous loamy-sand, and shows the usual large decrease in organic matter, C/N ratio, pH value and nutrient content. The *subsoil* grades into streaky or mottled red and yellow compact quartz-gravelly and micaceous sandy-clay. The red patches consist of powdery haematite; hard ironstone concretions are sparse. The reaction is highly acidic (pH 5.0), but characteristically less acidic at the lowermost depths.

The *parent granite* is not usually reached even at the 24-foot depth, although rotten rock, containing abundant quartz grains and white mica plates, together with iron-stained kaolin, may form a thick layer at the base of the profile. The lack of red coloration is doubtless caused by the low content of iron-bearing minerals in the original granite.

Two of the profiles (Nos. 7 and 8, Asuansi) contain sodium chloride (100 p.p.m.) in the lower layer, in addition to other salts, such as calcium nitrate, but the presence of these salts is not necessarily abnormal.

(5) *Metamorphic Yellow Earth Soil*: Profiles Nos. 6, 10, 11, 12.

Two of these soils (Nos. 11 and 12, Nkawkaw) appear to be derived from Upper Birrimian Greenstone (metamorphosed dolerite), whilst the other two (Nos. 6 and 10) are apparently derived from Lower Birrimian metamorphic sedimentary rock of undetermined type.

The four profiles are variable with regard to mechanical composition and the distribution of gravel in the different layers. The two greenstone profiles show gradually increasing amounts of gravel downwards, whilst the distribution of gravel in the other two is very irregular. All the profiles contain conspicuous hard or soft *ironstone concretions* in the lower layers. They are highly quartzose but not micaceous. Their colour is pale brownish-yellow, and red mottling is not so abundant as in the granite soil profiles.

The *surface soil* (0-6 ins.)—*see* table—is a dark brown sand, acidic in reaction (pH 5.7), and typically deficient in organic matter (1.6 per cent.). It is less than 50 per cent. saturated with lime, and its lime requirement for correcting acidity is about one ton ground limestone per acre. Nutrient status is about the same as that of the Granite Yellow Earth Soil, although differences exist in phosphate and potash contents, whose amounts appear, however, to be generally inadequate. The *subsurface soil* (6-12 ins.) is a very highly acidic, yellowish-brown, gravelly and sandy clay-loam, very deficient in organic matter and nutrients. The *subsoil* is a sandy and silty clay, containing concretions and quartz gravel. It is coloured reddish-yellow, mottled white, blue-grey and red. Organic matter penetrates deeply, but nutrient status is very low.

The *parent rock* is nowhere approached at the 6-foot depth, and a thick layer of concretionary gravel or orange-coloured "laterite" appears to cover it.

(6) *Alluvial Yellow Earth Soil*: Profiles Nos. 2, 4, 9, 16.

This varies in the kind of rock from which the alluvium was derived, but the soils possess certain features in common which distinguish them from the five other main types. Their chief characteristic is the almost entire absence of gravel, although the contents of the individual sand, silt and clay fractions are very variable. The alluvial soils tend to become more clayey when traced downwards; organic matter penetration is usually shallow.

The *surface soil* (0-6 ins.)—*see* table—is a dark brown, loose or powdery loamy-sand, variably acidic in reaction, and deficient in organic matter (1.3 per cent. only), whose carbon-nitrogen ratio is fairly high (9.6). Its degree of saturation by exchangeable lime is 52 per cent., and the lime requirement for neutrality is about $\frac{3}{4}$-ton of ground limestone per acre. Nutrients are very low in amount, available phosphate and potash averaging only 20 and 54 p.p.m. respectively. The *subsurface soil* (6-12 ins.) is yellow in colour, but its reaction and content of organic matter are nearly the same as those of the layer above, although nutrient contents are much lower, indicating a small degree of permanence of fertility. The *subsoil* (1-5 feet) is a greyish-yellow loamy-sand, occasionally containing small ironstone concretions, and usually mottled red, brown, yellow and white. Its reaction is very highly acidic (pH 5.0), and organic matter and nutrients are negligible in amount. One of the profiles (No. 16, Okrakwajo) shows a permanent water-table at 42 inches, below which the soil is alkaline and contains sodium chloride (330 p.p.m.), and probably nitrates in addition. Another profile (No. 9, Nkawe) also contains sodium chloride (310 p.p.m.) in the lowermost layer, and may suffer from impeded drainage. The remaining two profiles appear to be well aerated.

(V) Agricultural Relationships.

The detailed results of our previous investigations of the factors that distinguish "good" cacao soils from "bad" warrant an attempt to assess the fertility status of the Gold Coast soils so far examined, in terms of West Indian standards. A summary of the West Indian results has been presented in the introduction to the Chemical Section of the Fifth Annual Report on Cacao Research for 1935, at pp. 25--28. Whilst a large part of our cacao researches have involved environmental studies of the cacao tree in Trinidad (including studies of the water relations between the tree and the atmospheric and soil environments), a considerable amount of information has been obtained by means of soil analysis, soil surveys and manurial experiments, that has indicated the nutrient requirements of cacao. Thus provisional "*limits of adequacy*" have been fixed for various soil factors, as follows:—

Provisional Lower Limits of Adequacy.

(West Indian Cacao Soils; Surface 6-ins Layer).

		Sandy Soils.	Clay Soils.
Index of Texture.		0-25	25-60
Organic Matter	(per cent.)	3.0	4.0
Total Nitrogen	(per cent.)	0.20	0.25
Carbon-Nitrogen Ratio	(C/N)*	8.5	9.5
Available Phosphate	(P_2O_5, p.p.m.)	30	50
Available Potash	(K_2O, p.p.m.)	100	175
Degree of Acidity	(pH value)	5.8	6.0

* For yields of over eight bags, or 1,320 lb., of dry cacao per 1,000 trees, or 400 lb. per acre, for planting distance 12 × 12 ft.

It must clearly be recognised that these values are based solely on the scrutiny of a large number of results obtained by laboratory soil examination in the British West Indies, and that they do not take into account such factors as rainfall, land slope, drainage, exposure of soil to drying, incidence of diseases and pests, planting distance, age of trees, genetic strain of cacao, &c., all of which may affect the yielding capacity of the cacao tree. They refer strictly to the soil environment of cacao plantations such as exist in Trinidad, Tobago and Grenada. The nutrient limits have been repeatedly checked, however, by field manurial experiments, and by the diagnosis of symptoms such as marginal leaf-scorch*, which is regarded as an indicator of potash deficiency in the soil. At least the laboratory analyses serve to reveal cases of pronounced deficiency of nitrogen, phosphate and potash, and in this sense they are valuable as guides to manurial treatments.

Assessment of the Gold Coast Cacao Soils.

The classified data pertaining to the Gold Coast cacao surface soils presented in the table agree fairly closely with their general reputation. The eight examples above the line may be regarded as relatively "good" cacao soils, whilst the remaining eleven cases may be considered as increasingly "bad" or "poor".

All the *Voltaian Red Earth* soils appear to belong to the "good" category by virtue of their suitable reaction, their high contents of nitrogen and organic matter having high carbon-nitrogen ratio, and their high nutrient contents. The exceptional Aburi Red Earth soil (No. 1) derived from Akwapimian metamorphic rock (said to be "quartzite"), heads the list; the remaining "good" soils are Yellow Earth soils, two derived from granite* and one from Lower Birrimian metamorphic rock. All the *Alluvial Soils* belong to the "bad" category; they apparently include the worst soils of the series.

Compared with Trinidad cacao soils, only the first Gold Coast soil approaches the famous Chocolate Soil in inherent fertility. Most resemble somewhat the Brasso Sand and the Moruga Sand soils, which may be regarded as fairly productive though not particularly good. The "good" Gold Coast soils appear to be slightly inferior to average Tobago cacao soils, but distinctly inferior to average Grenada cacao soils, which however are much more clayey. The "bad" Gold Coast soils are evidently deficient in organic matter, available phosphate and potash, and are usually too highly acidic (pH 5.8). They would probably benefit by suitable organic and mineral manuring and liming. Field experiments, based on the laboratory findings, might be laid down in order to test the various indications.

One peculiar feature of the Gold Coast soils deserves special consideration, namely, the *phosphate status* of the Red Earth soil-types. It is well known that red ferruginous soils are capable of absorbing and firmly fixing large amounts of phosphate, which is apparently not easily available to plants. Their phosphate requirement is very high, and large initial dressings of phosphatic manure, and perhaps of lime in addition, may be needed in order to raise their fertility level. Subsequently, much smaller annual applications of phosphatic manure may be all that is necessary to maintain their ability to supply phosphate.

Red ferruginous soils apparently may also yield abnormally low values for "available phosphate" when tested by the Truog method, in which the extracting agent is very dilute (one hundredth of one per cent.) sulphuric acid, pH value 3.0.

* See the special article on Leaf-Scorch appearing in this Report.

* The Cape Coast Granite Yellow Earth soil-type is apparently regarded as much superior to the Metamorphic (Birrimian) Yellow Earth soil-type, whilst the Voltaian Red Earth soil-type, mainly occupying the Krobo District, is not considered to be so productive as the laboratory data would indicate, perhaps because of factors other than soil. About 40 per cent. of the Gold Coast cacao (namely, 120,000 tons per year) is produced by the Granite Yellow Earth Soil, and future extension of cacao plantings is likely to occur mainly over this type of soil (Information provided by E. L. Hay).

GOLD COAST CACAO SOILS.

SUMMARISED DATA FOR SURFACE 6-INS. LAYER. SITES ARRANGED IN ORDER OF FERTILITY, AS BASED ON LABORATORY DATA.

Prof. No.	Site.	Sand %	Index Text. I.T.	Reaction pH.	Org. Matt. %	C/N Ratio.	Elec. Cond. mhos. × 10 ^{6}		Av. P_2O_5	Av. K_2O	Age of Trees; Yrs.	Condition of Trees.	Soil Type.
							Av. Nutr.	Rate of Soln.	p.p.m.	p.p.m.			
1	Aburi	56	20	6.3	5.0	14.0	124	111	324	341	44	Good	RM
15	Samarg	66	8	7.4	3.5	11.6	245	202	71	252	24	V.G.	RV
18	Kwabea	78	3	7.1	2.1	9.5	245	115	58	268	32	Poor	RV
19	Amoyu	65	7	6.5	4.3	10.8	204	185	41	185	18	Good	YG
7	Asuarsi 1	75	4	7.0	3.5	15.4	213	160	174	103	20	Good	YG
6	Mbeim	39	27	6.6	3.8	11.8	162	235	26	64	22	Good	YM
14	Sesiamang	72	5	7.1	2.5	10.8	165	113	26	103	22	Good	RV
13	Bukrum	75	6	7.3	3.6	10.1	223	149	26	76	27	V.G.	RV
5	Kumasi	66	8	5.8	2.6	11.2	59	26	19	90	26	V.P.	RM
12	Nkawkaw 2	49	14	5.7	2.6	11.1	72	54	25	48	30	Poor	YM
11	Nkawkaw 1	49	12	5.8	1.1	8.9	95	108	21	79	19	?	YM
9	Nkawe	74	3	5.7	1.7	9.8	74	63	22	75	26	Good	YA
17	Cherechum	84	0	7.2	1.0	13.6	93	19	18	72	24	Good	RA
3	Efiduasi 2	73	3	5.6	2.1	11.8	44	44	20	53	23	Good	YG
4	Dotum	49	12	5.6	1.5	7.6	58	64	24	45	21	Fair	YA
10	Manhyia	88	0	5.7	1.2	10.7	62	72	21	39	20	F.G.	YM
8	Asuansi 2	78	4	5.3	1.2	10.6	48	12	19	51	24	Poor	YG
2	Efiduasi 1	78	1	6.3	1.0	9.8	40	30	16	57	25	Poor	YA
16	Okrakwajo	87	2	6.9	0.9	9.2	62	19	19	41	10	Poor	YA

SOIL TYPES:

RV: Voltaian Red Earth.

RM: Metamorphic Red Earth (Akwapim. or Lr. Birrim).

RA: Alluvial Red Earth.

YG: Granite Yellow Earth.

YM: Metamorphic Yellow Earth (Lr. or U. Birrim.).

YA: Alluvial Yellow Earth.

FOR COMPARISON: CACAO SOILS OF BRITISH WEST INDIES.

TRINIDAD:												
Chocolate Soil	36	43	7.2	6.0	9.6	216	175	343	309	—	V.G.	—
Brasso Sand	60	18	6.2	2.5	7.8	100	87	39	267	—	Good	—
Moruga Sand	62	15	5.7	2.9	10.5	—	35	19	128	—	F.G.	—
TOBAGO:												
Schist Loam	—	35	6.7	4.8	10.2	180	177	82	87	—	Good	—
Diorite Loam	—	39	6.4	4.7	10.2	175	160	30	94	—	Good	—
Alluvium	—	29	6.5	4.1	12.0	180	173	75	80	—	V.G.	—
GRENADA:												
Basic Igneous Soil	—	40	6.9	3.7	10.7	135	117	85	380	—	V.G.	—

LIMITS OF ADEQUACY—(Provisional Trinidad Standards).

SANDY CACAO SOILS:

Available phosphate (P_2O_5) 30 p.p.m.

Available Potash (K_2O) 100 p.p.m.

C/N Ratio (Yields of 400 lb. or over, per acre) 8.5 to 11.5

Thus, red soils growing rubber trees in Malaya may give Truog values as low as 1 p.p.m., though the trees are apparently not suffering extreme phosphate shortage. Hence the test may have to be modified for application to red ferruginous soils when sufficient further field evidence, based particularly on phosphate manurial experiments, has been accumulated. Evidence of this sort is being sought in Grenada. There is urgent need of specific phosphate manurial experiments on red ferruginous soils growing different kinds of tropical crops.

(VI) Summary.

(1) The main features of 190 soil samples collected from 19 soil profiles representative of important cacao soil-types occurring in the Gold Coast, have been determined by field observations and laboratory examination.

(2) The soils are grouped into Red Earths and Yellow Earths; within each group Alluvial types are separated from Sedentary types. The effects of the parent rocks have also been distinguished. In all, six soil-types have so far been differentiated.

(3) Red Earth soils derived from the *Voltaian Series* of Middle Devonian sedimentary rocks (which include calcareous strata) comprise the most distinctive class, some examples of which may be comparable in productivity with the better West Indian cacao soils.

(4) Yellow Earth soils derived from *Intrusive Cape Coast Granite* are also noteworthy. They are highly micaceous, though variable in their fertility.

(5) Two other Red Earth soil-types are derived respectively from *Lower Birrimian* (Pre-Cambrian) and *Akwapimian* (Pre-Mid-Devonian) metamorphic sedimentary rocks or their alluvial equivalents, and two other Yellow Earth soil-types are derived either from *Upper Birrimian* greenstone, *Lower Birrimian* metamorphic rocks, or from alluvial equivalents of the *Akwapimian* rocks or of various kinds of *granite*.

(6) Each of the six soil-types is described separately; the profiles are all very mature, the unaltered parent rocks occurring only at considerable depths. The soils are generally gravelly and very sandy; only two profiles are loamy. Sandiness generally decreases, whilst acidity increases greatly with depth. Nutrients are confined mainly to the surface 6-ins. layer.

(7) An attempt to assess the fertility of the soils in terms of laboratory data has been made on a basis of West Indian standards. The surface soils are tabulated in order of apparent fertility, and compared with certain cacao soil-types occurring in Trinidad, Tobago and Grenada.

(8) The special case of the availability of phosphate in Red Earth soils is stressed. The need for specific manurial field experiments, based on the laboratory data, is urged.

(2) MARGINAL LEAF-SCORCH OF CACAO.

ITS RELATIONSHIP TO SOIL POTASH DEFICIENCY. (WITH A NOTE ON THE ECOLOGY OF CACAO THRIPS).

By F. Hardy.

A Characteristic leaf symptom of cacao, which appears to be associated with deficiency in available soil potash, has been identified in the cacao cultivations of Trinidad, Tobago and Grenada. The appearance of this symptom is indicated in the frontispiece of this report in which Figure 1 represents an early stage in its development, and Figure 2, a late stage. The symptom may be described as a crenulate marginal leaf-scorch. It appears first near the apices of the mature, dark green leaves, and develops progressively, both inwards towards the midrib, and backwards towards the leaf petiole, along the margin. The affected areas gradually turn purplish-grey-brown in colour, and become membranous and brittle. The inner borders of the dead areas are lined with darker purplish-brown pigment, and small darker brown patches appear within them. Eventually the leaf is shed somewhat prematurely. Young leaves are not affected by leaf-scorch; the symptom is therefore most conspicuous in the field towards the end of the wet season.

Marginal leaf-scorch has been known to cacao planters for many years. Its prevalence in the Toco District, where hilly cacao lands occur near the sea, has given rise to the belief that it is caused by "sea blast". Its common occurrence in sheltered valleys some distance from the Toco sea-coast, and in other inland districts, such as the Montserrat and Rio Claro Districts, refutes this belief.

The evidence on which marginal leaf-scorch of cacao has been identified with a deficiency of available soil potash may be classified into four categories, namely, (A) sand pot cultures of cacao seedlings, (B) sand tub cultures of cacao cuttings, (C) soil surveys, (D) cacao leaf chemical analysis.

(A) Sand Cultures of Cacao Seedlings in Pots.

The first indication that cacao leaf-scorch is associated with potash deficiency was revealed by nutrition experiments conducted during 1934 by J. A. MacDonald (Chemist for Cacao Research). The results are described and illustrated by photographs in the Fourth Annual Report on

Cacao Research for 1934, at pp. 83 to 85. The leaf-scorch symptom appeared when the cacao seedlings had been growing for seven months in cultures in which potassium salts were omitted. It became more conspicuous until the end of the experiment after ten months' growth, when the plants became root-bound. None of the other cultures (lacking nitrogen, lacking phosphorus and complete nutrients) showed the leaf-scorch symptom. The potassium-starved seedlings were spindly in habit; growth in height and root development were normal, but the stem diameter was small, and the proportion of fine to larger roots was abnormally large.

(B) Sand Cultures of Cacao Cuttings in Tubs.

At about the same time as the pot cultures were started, cacao cuttings, propagated for us by the Botanical Department from clonal material, were transplanted into sixteen 50-gallon tubs containing English quartz sand (650 lb. of sand per tub), and watered until they had become established. In January, 1934, the tub cultures were divided into four groups, each consisting of a range of four cuttings of varying degrees of healthiness. Four specific nutrient treatments were subsequently applied to the different groups, namely, (A) complete nutrients, (B) lacking nitrogen, (C) lacking potassium, and (D) lacking phosphorus. The composition and method of application of the nutrient solutions, and the kind of quartz sand used were similar to those successfully employed by Dr. T. Wallace at the Long Ashton Research Station, University of Bristol, England, in his studies on the nutrition of the apple and other temperate fruit trees. The diluted culture solutions were applied twice a week, and the tubs were flushed with fresh water once a week in order to remove excess of salts. The nitrogenous solution applied to two of the four cultures of each of the three nitrogen treatments, (A), (C) and (D), contained nitrate nitrogen, and that applied to the other two contained ammonium nitrogen.

After one year's growth, the cacao plants receiving no nitrogen were smaller in size and their leaves yellower than those of the three other treatments. During 1935, the nitrogen-starved plants showed little further growth. In June, 1935, the first signs of marginal leaf-scorch appeared in the cultures lacking potassium. By the end of 1935, the foliage of the cultures lacking phosphorus had become sparse, and the leaves were grouped at the ends of the branches, which had become thin, whippy and pendulous. No differences could be discerned between the nitrate and the ammonium-treated plants. During 1936, the characteristic symptoms of the cultures lacking each of the three elements became intensified. At this time, the nitrogen-containing nutrient cultures supported vigorous trees, and flowers and young fruits had appeared. No pods greater than quarter full size developed, and premature shedding unfortunately prevented the collection of ripe beans for chemical analysis.

In order not to impose restrictions on growth, extra nitrate was added to each nitrogenous culture solution during the early part of 1936. In April 1936, leaf-scorch was observed to be very severe in the potassium-starved cultures, but traces of the symptom, thought to be caused by the increased dosage of nitrogen relative to potash, appeared in the complete nutrient culture (A) and in the phosphorus starved culture (D). The extra nitrogen treatment was accordingly discontinued. In May, 1936, additional potash was applied to two of the four cultures of each of the three nitrogenous treatments, (A), (C), (D), as a deliberate attempt to reduce leaf-scorch, but no improvement occurred.

In August, 1936, a further attempt was therefore made to counteract the development of leaf-scorch by completely removing the foliage by pruning, and by supplying the elements which had hitherto been lacking in the specific treatments. The object of this change in procedure was to discover whether the symptom could be reduced by potash nutrition. A complete nutrient solution was applied to all the (A) cultures, and to two of the four cultures of each of the three other treatments. In addition, extra potash was also applied to these cultures. At the present time (March, 1937) new foliage has developed on most of the plants, but no leaf-scorch has yet appeared. The oldest leaves (now seven months old), have not yet reached maturity, so that there is still time for the symptom to develop. It is thus unwarrantable to state, at this juncture, that the addition of potassium to cultures previously lacking this element has "cured" the leaf-scorch although later observations, carried out, say in June, 1937, might provide final evidence.

Partial pruning of the cultures was performed on three occasions (namely, April and November, 1935, and June, 1936), in addition to the last severe pruning in August, 1936. The total weights of dry material (wood and leaves) collected in the prunings, expressed also as percentages of the dry weight of the material collected from the complete nutrient cultures, were:—

	Total Wt. (gr.)			Percentages.		
	Wood.	Leaves.	Total.	Wood.	Leaves.	Total.
Complete ..	269	618	**887**	100	100	**100**
Lacking Nitrogen ..	30	78	**108**	11	13	**12**
Lacking Potassium ..	154	433	**587**	57	70	**66**
Lacking Phosphorus..	199	455	**654**	74	74	**74**

The leaf material collected at the first pruning in April, 1935, when the plants were 16 months old, has been chemically analysed. The results

Table I.

RELATIONSHIP BETWEEN LEAF-SCORCH AND AVAILABLE POTASH FOR DIFFERENT CACAO SOIL-TYPES IN TRINIDAD, TOBAGO AND GRENADA.

(Averaged Laboratory Data for Surface 6-ins. Layer).

Soil-Type.	Index of Texture.	pH value	Org. Matter %	C/N Ratio	Total Nitrogen. %	Avail. Phosphate (P_2O_5) (p.p.m.)	Avail. Potash (K_2O) (p.p.m.)	Leaf Scorch.
(A) ALLUVIAL SOILS. (I) TRINIDAD: NORTHERN RANGE REGION.								
(1) River Estate Sand (17)	16	5.9	1.8	8.4	0.13	21	66	Marked
(2) River Estate Loam (8)	26	5.7	2.0	8.0	0.14	21	59	Marked
(3) Matura Clay (2)	48	6.5	4.0	7.4	0.26	9	57	Severe
Do. (2)	49	5.5	3.7	7.8	0.24	16	85	Marked
Do. (2)	58	4.9	5.3	8.0	0.39	17	103	**None**
(B) SEDENTARY SOILS.								
(4) Western Mica-Schist Sand (2)	15	4.7	2.7	9.3	0.17	24	51	Marked
Do. do. (2)	15	5.1	3.0	10.5	0.17	26	190	Slight
(5) Western Mica-Schist Loam (2)	30	4.9	2.2	8.4	0.15	13	83	Severe
Do. do. (2)	28	5.2	2.5	8.3	0.18	19	110	**None**
(6) Toco Quartz Grit Loam (3)	24	5.6	3.2	8.1	0.22	27	73	Severe
(7) Toco Calc. Schist Loam (4)	22	6.3	2.2	6.0	0.19	79	62	Severe
(A) ALLUVIAL SOILS. (II) TRINIDAD: NORTHERN PLAIN REGION.								
(1) Sangre Grande Loam (3)	32	4.6	3.0	8.7	0.21	17	73	Severe
Do. do. (3)	30	5.0	2.9	9.2	0.18	18	69	Marked
Do. do. (5)	29	4.9	2.0	7.4	0.16	18	60	Slight
(2) Sangre Grande Clay (12)	39	5.1	3.3	8.9	0.21	17	74	Severe
Do. do. (11)	46	4.9	3.7	8.5	0.25	18	89	Marked
Do. do. (11)	46	4.5	3.5	8.2	0.25	18	94	Slight
(3) Caroni Vegas Clay (7)	34	5.1	2.9	8.4	0.20	17	97	Slight
Do. do. (12)	38	5.5	3.3	8.7	0.22	24	112	**None**
(B) SEDENTARY SOILS.								
(4) Caroni Sand (4)	24	5.1	2.0	8.4	0.14	12	81	Severe
Do. (2)	14	5.1	1.8	8.4	0.13	20	133	Slight
(A) ALLUVIAL SOILS. (III) TRINIDAD: CENTRAL RANGE REGION.								
(1) La Vega Sand (10)	20	6.1	2.5	9.0	0.16	25	91	Slight or None
(B) SEDENTARY SOILS.								
(2) Chocolate Clay-Loam (2)	48	5.8	5.4	9.3	0.34	56	124	Marked
Do. do. (2)	35	6.6	5.4	10.8	0.29	41	324	**None**
(3) Brasso Sand (2)	25	6.3	3.0	9.9	0.18	38	63	Marked
Do. (2)	20	6.2	3.6	11.2	0.19	20	106	Slight
(4) Brasso Clay (2)	38	5.8	3.5	8.5	0.24	18	82	Severe
Do. (4)	37	5.8	3.3	9.0	0.22	23	75	Marked
Do. (2)	51	6.3	3.5	8.6	0.24	19	220	**None**
SEDENTARY SOILS. (IV) TRINIDAD: SOUTHERN PLAIN REGION.								
(1) Princes Town Marly Clay (2)	61	6.8	8.8	10.8	0.47	30	174	Slight
(2) Naparima Red Clay (3)	35	5.9	3.2	8.7	0.21	21	86	Marked
(3) Moruga Silty-Sand (6)	22	5.7	2.6	8.4	0.17	19	90	Slight
SEDENTARY SOILS. (V) TOBAGO: SOUTHERN REGION.								
Diorite Brown Loam (4)	28	6.5	3.4	10.3	0.19	13	65	Severe
Do. do. (5)	30	6.5	3.2	10.5	0.17	86	100	Slight
SEDENTARY SOILS. (VI) GRENADA: WESTERN REGION.								
Andesite Red Loam (2)	46	7.4	3.9	9.4	0.24	46	76	Severe
Do. do. (4)	40	7.2	3.8	9.9	0.21	28	134	Slight
Do. do. (1)	20	7.1	2.8	10.8	0.15	54	319	**None**
PROVISIONAL LOWER LIMITS OF ADEQUACY: Surface 6-ins. layer.								
Sandy Soils	0	5.8	3.0	8.5*	0.20	30	100	
Loamy Soils	21	5.9	3.5	9.0*	0.22	40	150	
Clayey Soils	36	6.0	4.0	9.5*	0.25	50	175	

* C/N Ratio for yields over 8 bags (1,320 lb.) dry cacao per 1,000 trees or 2.7 bags per acre.

are discussed in a later section of this article. It should be noted that the " lacking " cultures each provided appreciable amounts of the deficient elements, because tap water throughout was used, and considerable quantities of disintegrated matter and insect fras had fallen onto the cultures from the roof of their shelter, which was lightly thatched with coconut leaves.

(C) Soil Surveys and Leaf-Scorch.

During the course of the soil survey of Trinidad since the time when leaf-scorch was first suspected to be associated with potash deficiency, observations have been made of occurrences of the symptom within areas of recognisable soil-types by officers concerned in cacao research. Special soil samples (surface six-inch layer of soil, composited from auger-cores obtained at ten spots) have been collected within these areas, and examined in the laboratory. This special series of soil samples has been designated " NPK " samples; some 187 such samples have so far been analysed. The laboratory results are summarised in Table I, in which the data are arranged under the chief soil-types occurring in different geographical regions. The figures in brackets after the name of the soil-type indicate the number of composite soil samples whose analytical results were averaged. The last column gives the degree of severity of leaf-scorch.

The main conclusions to be drawn from this investigation are :—

(I) Northern Range ; Trinidad.

Leaf-scorch has been observed in cacao plantations representative of all the chief soil-types occurring in this region, both in the valley flats and on the hillslopes. The most widespread occurrence of leaf-scorch has been recorded in the Toco District, where the symptom has long been known as " sea-blast ". The soil-types usually associated with leaf-scorch are the *Toco Quartz-Grit Loam*, and the non-calcareous subdivision of the *Toco Schist Loam*. All the soil samples belonging to these types so far examined contain low contents of available potash (around 65 p.p.m.). The soils are sandy, but the average potash content for soils of similar texture supporting healthy cacao trees in other parts of Trinidad is around 125 p.p.m., which may provisionally be accepted as the lower limit of potash adequacy for sandy-loam soils. The Toco soils otherwise seem not to be deficient in organic matter, nitrogen and available phosphate, although their nutrient status cannot be regarded as satisfactory.

Another Northern Range area where leaf-scorch is conspicuous is River Estate, a *sandy or silty alluvial* flat in the Diego Martin Valley, west of Port-of-Spain. Here also available potash deficiency is well marked, the average value being less than 65 p.p.m.

The only area of *clayey* alluvial soil so far examined in the Northern Range region lies in the Matura District of north-east Trinidad, where leaf-scorch is very conspicuous, and appears invariably to be associated with low values for soil potash (around 70 p.p.m.). The lower limit for potash, provisionally accepted for clay soils is about 150 to 175 p.p.m.

Soils of the Northern Range region supporting cacao free from leaf-scorch have usually been found to contain over 100 p.p.m. of available potash, which conforms with the standard for potash adequacy for sandy soil-types.

(II) Northern Plain ; Trinidad.

Cacao is grown in this region mainly in the great alluvial basin of the Sangre Grande-Oropouche District, and in the flats of the tributaries of the Oropouche and Caroni Rivers (*e.g.*, Cunapo, Cumuto, Tumpuna, Talparo and Caparo Rivers). Leaf-scorch here is very common, and again seems to be associated with a low content of available potash (around 80 p.p.m.). The soils are *alluvial loamy-clays*, for which the lower limit for potash content has provisionally been fixed at 125 to 150 p.p.m. The soils are also generally deficient in available phosphate (around 18 p.p.m., provisional limit of adequacy, 35 p.p.m.); they are very highly acidic (reaction value less than pH 5.0), and lacking in lime, though well supplied with organic matter and nitrogen.

Where cacao is grown on hillslopes within this region, the chief soil-type is *Caroni Sand*, an infertile, potash-deficient soil, quite unsuited to cacao, which shows leaf-scorch wherever established.

(III) Central Range ; Trinidad.

Within the Montserrat District of Central Trinidad, leaf-scorch is uncommon, and where present, it is only sporadic and slight in intensity. The rich *alluvial* soils here are usually well supplied with potash, although some are on the border-line of deficiency.

Within areas of *Chocolate Soil* (by far the most fertile soil in the whole of Trinidad), leaf-scorch has indeed been recorded, but it has been found associated only with a potash-deficient brown soil, not typically " Chocolate ", derived from a calcareous parent rock devoid of the greenish-grey, potash-bearing mineral, glauconite. Otherwise the Chocolate Soil seems not to support cacao showing leaf-scorch ; its available potash content is extremely high and ranges from 130 to over 900 p.p.m. (average for 20 samples, 260 p.p.m.) ; its other attributes are almost ideal.

The next most fertile Central Range soil, namely *Brasso Sand Soil*, occasionally supports trees showing leaf-scorch, associated with a low potash content (63 p.p.m.). The range of potash values for this soil-type is wide, namely, 75 to over 400 p.p.m. (average for 15 samples, 190 p.p.m.).

The *Brasso Clay* soil-type also shows a wide potash range, but generally it is well supplied with available potash (around 160 p.p.m.) ; leaf-scorch is rare, but the few cases investigated show it to be associated with low available potash values (80 p.p.m.).

(IV) Southern Plain ; Trinidad.

The most successful cacao soil-type in this region is *Moruga Silty-Sand Soil*, occurring around Penal, Siparia and Moruga. The available potash content is variable, ranging around 140 p.p.m., which is regarded as adequate for this textural type. Occasionally, leaf-scorch is discernible ; the six cases examined show slight symptoms, associated with an available soil potash content of about 90 p.p.m. The soil may also be deficient in available phosphate (20 p.p.m. ; limit of adequacy for phosphate, 30 p.p.m.).

The *Princess Town Marly-Clay Soil*, widespread in the Rio Claro-Tableland District, is a very distinctive " humus carbonate " black soil, remarkably deficient in available phosphate (only 17 p.p.m.), but generally extremely rich in organic matter and nitrogen. Its available potash content is variable ; occasionally leaf-scorch appears, notably on trees planted on hill crests where the parent marlstone occurs at shallow depths. The average potash content for 12 representative samples of the black marl soil was found to be 230 p.p.m., but values below 170 p.p.m. have been recorded, and, in two of these cases, slight leaf-scorch was observed. To what extent these cases may be attributed to a very high content of nitrogen in proportion to a low phosphate content and a slight deficiency of available potash, or to a high lime content which may depress potash uptake, cannot be decided on the available evidence.

The other important soil-types of the Southern Plain Region, namely, *Naparima Red Clay* and the so-called *Calcareous Green Clay*, are occasionally utilised for growing cacao, but the Naparima Clay is unsuitable for cacao, being highly gypseous. Its available potash content is variable (80 to 250 p.p.m., average, 170 p.p.m.), though generally adequate ; leaf-scorch has been noted in three cases where the soil contained about 86 p.p.m. available potash. The *Calcareous Green Clay Soil* resembles the Princes Town Marl Soil, and leaf-scorch is seldom associated with it.

(V) Tobago.

The cacao soils of Tobago comprise three distinctive types not well represented in Trinidad, namely, (1) a *yellow-brown loam*, derived from *basic igneous rock* (diorite or augite andesite), (2) a *greenish-brown* to *orange loam*, derived from *metamorphosed sedimentary rocks*, resembling certain of the Northern Range schists, and (3) *dark-brown alluvial soils*, derived from the same parent materials, or from the sedentary soils (hillwash). The fertility of these soils is high, organic matter and nitrogen being usually abundant and the reaction nearly neutral. Available phosphate is variable, though usually high, but available potash tends to be deficient. Leaf-scorch is common in some areas, and fairly widespread in the cacao cultivations. Out of nine cases examined, Diorite Brown Loam soils, associated with severe leaf-scorch, contained only 65 p.p.m. of available potash, and those associated with slight leaf-scorch contained about 100 p.p.m. ; in other respects these soils appear to be satisfactory.

(VI) Grenada.

The cacao soils of Grenada are different both from those of Trinidad and those of Tobago. They are mainly *red-brown* or *red clay-loam*, derived from *augite or hornblende andesite* and *basalt*, occurring in the windward " middle belt " of annual rainfall between 80 and 100 inches. Cacao is also grown on *brownish-grey sandy-loam* soil, derived from *volcanic agglomerate, ash and tuff*. In general, the Grenada cacao soils are rich in organic matter and nitrogen, their reaction is nearly neutral, but available phosphate content is usually deficient in the less productive soils. Available potash content is extremely plentiful, mainly because of the particular nature of the parent rocks, and the general practice of manuring. The average value for 20 productive soils was found to be 430 p.p.m., and for 16 less productive soils, 325 p.p.m., values which greatly exceed the provisional limit of adequacy for loamy cacao soils, namely about 150 p.p.m. available potash.

Occasionally leaf-scorch appears in the cacao cultivations ; the six cases so far examined proved its association with clayey soils containing relatively small amounts of available potash (around 110 p.p.m.), but certain apparent discrepancies have been revealed which require further investigation. The facts that tillage is practised in many of the cacao fields of Grenada, and that the red soils are often very friable, so that root penetration may be deep, may involve the lower layers of soil in the nutrition of cacao, so that laboratory examination of the surface 6-inch soil alone may not be sufficient.

General Conclusions.—Averaged data for sandy, loamy and clayey soils, derived from the detailed soil analyses, are presented in Table II, together with provisional lower limits for adequacy based on these and numerous additional analyses. The data demonstrate that the most obvious nutrient factor associated with leaf-scorch is a *deficiency of available soil potash*, although its magnitude may vary in the different textural types.

Manurial Experiments.—Based chiefly on the indications gained by soil analysis, a large number of manurial experiments with phosphatic and potassic manures and lime have been initiated in the cacao cultivations of Trinidad, Tobago and Grenada, by officers of the Department of Agriculture ; they are described in a following section of this report.

Several of the potash experiments have been laid down on areas where leaf-scorch is prevalent, for example, River Estate. So far, no alleviation of the symptom has yet been recorded, even though certain experiments have been running for two or three years. Evidently the application of potassic manure to potash-deficient cacao soil

Table II.

COMPARISON OF SOILS OF DIFFERENT LEAF-SCORCH REPUTATION AND TEXTURE.

(Summarised Data for Surface 6-ins Layer.)

Leaf-Scorch	Index of Texture (I.T.)	Degree of Acidity (pH)	Total Organic Matter %	Carbon Nitrogen Ratio	Total Nitrogen %	Avail. Phosphate (P_2O_5) (p.p.m.)	Avail. Potash (K_2O) (p.p.m.)
SANDS (I.T. 0-20)							
Marked (19)	16	5.7	1.9	7.8	0.13	21	62
Slight (16)	19	5.9	2.6	9.4	0.16	21	110
WEIGHTED MEANS (51)	**17**	**5.8**	**2.2**	**8.9**	**0.15**	**21**	**84**
No Leaf-Scorch (2)	**20**	**6.1**	**2.8**	**10.0**	**0.15**	**30**	**120**
Provisional Lower Limits of Adequacy	0	5.8	3.0	8.5	0.20	30	100
LOAMS (I.T. 21-35)							
Severe (18)	26	5.6	2.7	8.3	0.18	30	70
Marked (16)	28	5.7	2.5	8.6	0.17	23	62
Slight (25)	29	5.4	2.6	8.6	0.17	31	87
WEIGHTED MEANS (59)	**28**	**5.6**	**2.6**	**8.5**	**0.18**	**29**	**75**
No Leaf-Scorch (4)	**30**	**5.9**	**3.5**	**9.0**	**0.23**	**30**	**217**
Provisional Lower Limits of Adequacy	21	5.9	3.5	9.0	0.22	40	150
CLAYS (I.T. 36-60)							
Severe (18)	41	5.6	3.5	8.7	0.22	17	73
Marked (20)	42	5.0	3.6	8.2	0.24	22	85
Slight (17)	46	5.4	4.2	8.9	0.27	21	113
WEIGHTED MEANS (55)	**43**	**5.3**	**3.7**	**8.6**	**0.24**	**20**	**90**
No Leaf-Scorch (16)	**42**	**5.5**	**3.6**	**8.6**	**0.29**	**22**	**124**
Provisional Lower Limits of Adequacy	36	6.0	4.0	9.5	0.25	50	175

does not necessarily " cure " leaf-scorch immediately, athough the productivity of the tree may be greatly increased, even in the following crop. Presumably a considerable period of time is required for the raising of the potash status of the tree, and for the attainment of new equilibria between the nutrient factors that are affected by the increased supply of potash in the soil.

(D) Leaf Analysis.

In order to obtain information regarding the possible relationship between leaf-scorch and the chemical composition of the leaf tissues, ash analyses were made of scorched leaves and of healthy normal leaves, obtained either from the same tree or from differently-affected trees growing in the same vicinity. Leaves were also analysed from the tub cultures described in a previous section. In every case the midribs and the larger veins, as well as the scorched dead tissue, were removed before oven drying.

It is generally conceded that leaf ash analysis cannot be considered as a satisfactory method of measuring nutrient uptake by the plant, nor of assessing available nutrient supplies in the soil. The complex physiological processes of nutrient absorption by the root, and of transportation, fixation and utilisation within the plant, are very imperfectly understood. Nor can it be assumed that manurial ingredients added to the soil will gain direct access to the plant, because profound reactions, replacements and interchanges, may proceed in soil which is manured, so that, except perhaps in pure sand cultures, the added nutrients may be withheld, while others already present in the soil may be released and rendered available. Thus, in certain cacao manurial experiments in Trinidad, the addition of superphosphate caused an increased uptake of *potash* from the soil, but not of phosphate.

" Luxury consumption " of nutrients occurring in excess in the soil may also proceed, so that the amounts present in the leaf or fruit may bear no relationship to the plant's needs nor to its growth responses. The notion of " balanced nutrition " nevertheless appears to have some physiological foundation, so that determinations of *nutrient ratios* in leaf tissues may furnish evidence of deficiencies, particularly if these ratios are compared for abnormal " starved " plants and for healthy plants.

In our investigations, distinction has been drawn between healthy and scorched leaves occurring (A) on *different* trees growing in the same soil-type, and (B) on the *same* tree growing in different soil-types. Analytical data for the two kinds of leaf material are presented in Table III.

Table III.

CHEMICAL COMPOSITION OF ASH OF SCORCHED AND HEALTHY CACAO LEAVES.

(Analytical Data for Ash Components.)

Intensity of Leaf Scorch.	Total Ash	Sol. Ash	Nitrogen N	Composition of Leaf Ash. Phosphate P_2O_5	Potash K_2O	Lime CaO	Mgn. MgO	Nutrient Ratios. N/P_2O_5	N/K_2O	K_2O/CaO	MgO/CaO	Sum of bases.
	% Dry Matter.		Per cent. of Total Ash									
(A) LEAVES FROM DIFFERENT TREES.												
(I) SAND CULTURES IN TUBS: Cacao plants 16 months old.												
Severe (-K)	9.5	—	29.5	7.7	21.2	22.0	14.1	3.8	1.43	1.0	0.64	57.3
None (Compl.)	11.6	—	24.4	5.0	31.0	13.3	7.8	4.9	0.80	2.1	0.59	52.1
None (-P)	10.7	—	24.9	4.4	36.8	13.8	8.6	5.7	0.68	2.7	0.62	59.2
None (-N)	11.8	—	14.2	6.2	28.7	14.9	12.7	2.3	0.49	2.0	0.85	56.3
(II) RIVER ESTATE: Manurial Expt., Field 8A:												
Slight (-K)	6.7	—	34.3	10.1	29.9	13.9	11.4	3.4	1.15	2.1	0.82	55.3
? (Compl.)	7.5	—	30.8	8.6	33.9	12.0	10.7	3.6	0.91	2.8	0.89	56.6
? (-P)	7.6	—	30.2	9.0	37.0	11.0	10.1	3.3	0.81	3.4	0.92	58.1
? (-N)	7.6	—	29.5	8.8	36.9	9.9	10.2	3.4	0.80	3.7	0.97	57.0
Slight (O)	6.7	—	33.0	9.5	32.2	12.0	11.1	3.5	1.03	2.7	0.92	55.3
(III) Toco: El Carmen Estate.												
Severe	12.2	7.2	17.5	2.6	10.7	18.6	11.8	6.7	1.63	0.6	0.63	41.1
Slt. or None	10.9	7.1	22.0	3.5	15.8	17.5	12.7	6.3	1.39	0.9	0.73	46.0
(IV) SANGRE GRANDE: El Reposo Estate.												
Slight	8.6	6.6	29.3	5.5	27.2	13.5	13.7	5.4	1.10	2.2	1.01	54.4
(V) RIO CLARO: Poole Estate.												
None	9.8	—	22.8	3.6	20.7	20.9	10.9	6.5	1.12	1.1	0.52	52.5
(VI) TOBAGO.												
Severe	12.1	5.1	16.2	3.3	9.2	13.7	10.9	4.8	1.76	0.7	0.79	33.8
(VII) GRENADA: Balthazar Estate.												
Severe	15.8	5.5	9.1	1.7	4.2	14.3	10.6	5.2	2.17	0.3	0.74	29.1
Slt. or None	10.3	6.3	19.2	4.0	16.9	17.3	13.8	4.8	1.14	1.0	0.79	48.0
(B) LEAVES FROM SAME TREE.												
(I) SANGRE GRANDE: Oropuche, Hasnally's Holding.												
(1) Severe	12.3	6.4	16.8	2.5	9.7	15.0	12.1	6.6	1.72	0.6	1.2	36.8
Slt. or None	9.5	6.6	24.0	3.8	17.2	16.7	15.4	6.3	1.39	1.0	1.1	49.3
(2) Severe	12.6	8.2	16.4	2.1	9.8	20.2	10.9	8.0	1.67	0.5	1.8	40.9
Slt. or None	9.4	7.4	24.8	3.7	17.9	20.2	12.4	6.7	1.39	0.9	1.6	50.5
(3) Slight	9.7	6.7	21.6	2.7	24.3	12.3	12.0	8.1	0.89	2.0	1.0	48.6
Slt. or None	9.0	7.0	27.1	3.2	26.1	12.1	13.3	8.4	1.04	2.1	0.9	51.5
(II) RIO CLARO: Poole Estate.												
Slight	12.1	8.6	17.4	2.4	14.5	26.0	8.2	7.3	1.20	0.6	3.2	48.7
None	11.1	8.0	19.0	2.9	20.2	23.0	8.3	6.6	0.94	0.9	2.8	51.5
MEANS: (Toco, Sangre Grande, Rio Claro, Tobago, Grenada.)												
Severe	**13.2**	**7.3**	**14.8**	**2.5**	**8.4**	**16.0**	**11.2**	**6.0**	**1.82**	**0.5**	**0.70**	**35.7**
Slight or None	**9.8**	**6.7**	**23.6**	**4.0**	**20.4**	**16.9**	**12.9**	**6.1**	**1.18**	**1.3**	**0.76**	**50.2**

(I) SAND CULTURE EXPERIMENT.

The analytical data show great differences between the contents of nitrogen, potash and lime of the leaves of potash-starved cultures as contrasted with those well supplied with potash. The low potash content of the scorched leaves is offset by a reciprocally high lime content and a high nitrogen content, which are clearly revealed by the ratios for potash to lime and nitrogen to potash. Leaf-scorch seems especially to be associated with a high nitrogen-potash ratio (which numerically exceeds 1.0), and a low potash-lime ratio.

Table IV.

CHEMICAL COMPOSITION OF ASH OF NORMAL CACAO LEAVES OF INCREASING AGE.

Age of Leaf.	Good Plot.						Bad Plot.					
	Water in Fresh Leaf Per cent.	Total Ash in Dry Matter Per cent.	Composition of Ash				Water in Fresh Leaf Per cent.	Ash in Dry Matter Per cent.	Composition of Ash			
			N	P_2O_5	K_2O	N/K_2O			N	P_2O_5	K_2O	N/K_2O
			Per cent. Ash.						Per cent. Ash.			
Very Young	81.5	9.3	33.8	9.7	35.2	0.96	80.7	8.1	40.1	10.6	35.9	1.12
Young	66.6	9.9	23.9	5.1	26.6	0.89	66.8	8.3	28.5	5.1	27.9	1.04
Mature	61.2	12.3	19.0	2.7	15.1	1.26	61.6	12.3	19.9	2.5	14.2	1.42
Very Old	**58.1**	**13.5**	**17.8**	**2.5**	**11.0**	**1.63**	**59.5**	**13.7**	**17.4**	**2.5**	**11.0**	**1.55**
FOR COMPARISON. Scorched .... (Means of All)	—	**13.2**	**14.8**	**2.5**	**8.4**	**1.82**						

NOTE :—(1) the rapid *decrease* in water content and nitrogen, and in ash components (particularly potash) as cacao leaves mature and become senescent, and the great *increase* in nitrogen-potash ratio.
(2) the close similarity between very old normal leaves and severely scorched leaves.

It is probable that the chemical composition of a scorched cacao leaf is merely that of a senescent leaf, in which partial drying has occurred, accompanied by reabsorption by the tree of mineral components. That this may be the case is indicated by the data in Table IV, in which the partial chemical composition of normal unscorched cacao leaves of increasing age is compared with that of severely-scorched leaves. It will be noted that the very old *normal* leaves show similar composition to severely scorched leaves.

The reabsorption of mineral elements from foliar tissues that have reached senescence has recently been demonstrated by Phillis and Mason in their studies on transport in the cotton plant (*Annals of Botany*, 1936, pp. 679-698).

During the wilting of the corolla of the cotton flower, nitrogen, phosphorus, potassium, magnesium and chlorine (but to a very much lesser extent, calcium) were found to be rapidly exported into the parent fruiting branch.* Evidently, during senescence, the ratio of potassium to calcium, and of magnesium to calcium should diminish greatly, whereas the ratio of nitrogen to phosphate (both largely reabsorbed) should remain much more constant. These features are indeed strikingly shown by the data for scorched and unscorched leaves produced in the sand cultures, thus supporting the view that scorching is merely an indication of premature senescence.

* The actual losses recorded by Phillis and Mason from the corolla of the cotton flower are, nitrogen, 56; phosphorus, 45; potassium, 24; magnesium 12, and calcium only 6 per cent. of the initial contents of these elements.

The wilting of flowers is preceded by an intense hydrolysis of protein, and as much as two-thirds of the nitrogen present may be exported within 24 hours (*loc cit.*). Hence nitrogen loss may greatly exceed loss of potassium, so that the nitrogen-potash ratio ought greatly to *decrease* during senescence, if the processes be the same in green leaves as in petals. Actually, however, the data for sand-culture cacao leaves show a significantly much *higher* nitrogen-potash ratio for scorched than for normal leaves, which may imply either (1) that nitrogen is *not* exported as rapidly as potash, (2) that the potash content of leaves liable to scorching is initially much less than that of normal leaves, so that lesser gross amounts of potash are removable, or (3) that the nitrogen content of scorchable leaves is greater than that of normal leaves. The analytical data do not permit a definite conclusion to be drawn as to which of these three explanations is correct, but it is evident that liability to leaf-scorch in some way is linked with the nitrogen and potash relations of the cacao leaf. Its close association with deficiency of soil potash supports this contention, and favours the view that scorch is partly caused by a low potash content of the leaf tissues.

While the exportation of solutes is proceeding from a wilting flower, colloidally-bound water is being converted into free water, implying a rapid collapse of the "protoplasmic organisation" of the cells (*loc cit.*); this is accompanied by a drying-out of the tissues of the corolla. Assuming similar changes to occur in green leaves, any condition within the leaf that is conducive to protoplasmic breakdown should cause premature senescence and desiccation, the drying-out process presumably starting near the periphery of the

leaf at places most remote from the petiole. The phenomenon of leaf-scorch complies with such conditions. It is believed that protoplasmic stability in some way is partly controlled by metallic elements, notably potassium and calcium, and experimental evidence is available to prove that the rate of transpiration of a green leaf is greatly affected by its potash content. Furthermore, leaf potash and leaf lime contents appear to be reciprocally related, high potash content invariably being associated with low lime content, and *vice versa*.

The whole problem of the cause of leaf-scorch is thus extremely complex, and, although the available evidence points to "unbalanced" nutrition (especially in connection with potash, lime and nitrogen), much further research is required before the exact conditions causing the development of the symptom can be precisely defined.

(II) River Estate Manurial Experiment.

The analytical data for ash composition as affected by plot treatments, when compared with those for sand-culture treatments, are seen to conform remarkably closely. The sandy soil was initially rich in nitrogen, but deficient in available potash and phosphate. Slight leaf-scorch affected the trees of the whole experimental area when the manurial treatments were first applied, but the extent to which the treatments may have suppressed the symptom is not yet known with certainty.

(III) Toco ; Estate Conditions.

The data for leaf composition for this area show some puzzling discrepancies when compared with data for sand cultures and for the River Estate manurial experiment. The material analysed was not entirely satisfactory, because the leaves said to show little or no scorching were obtained from trees growing in the same potash-deficient soil as those producing typically scorched leaves. Nitrogen, phosphate and potash contents of leaf dry matter are relatively low in both cases, but nitrogen-potash ratios are high, though definitely higher in the scorched leaves, while potash-lime ratio is lower, as in cases previously considered. The peculiar soil conditions obtaining in the Toco cacao area requires special detailed study.

(IV) Sangre Grande ; Estate Conditions.

The analytical data for scorched leaves are very similar to those for sand cultures and for River Estate, except that leaf lime content appears to be exceptionally low. Nitrogen-potash ratio exceeds 1.0, which seems to be the most consistent criterion for identifying liability to scorching. The soil is very highly acidic and deficient in lime and phosphate ; field manurial experiments involving liming are suggested as likely to yield information regarding the conditions conducive to scorching.

Comparison of analytical data for scorched and normal leaves obtained *from the same tree* (lower part of Table III), in all cases but one, reveals differences conformable with those obtaining in other contrasted cases already considered. Severe leaf-scorch again is associated with high nitrogen-potash ratio and low potash-lime ratio.

It should be particularly noted in the case of Sangre Grande material that the chemical composition and nutrient ratios for the leaves showing no obvious signs of scorch at the time of sampling *closely approximate* to those for the scorched leaves occurring on other branches of the same tree. This indicates in particular that a low gross potash content, a high nitrogen-potash ratio, and a low potash-lime ratio are definitely associated with a tendency towards leaf-scorch, and that these features are not merely a *result* of the leaf-scorch condition.

(V) Rio Claro ; Estate Conditions.

The data call for no special comment ; they conform with the previous data, though lime contents are somewhat high and potash contents somewhat low, as would be expected for cacao growing in calcareous soil.

(VI) Tobago ; Estate Conditions

The most striking feature shown by the data for severely-scorched leaves is their extremely low potash content. The high percentage of total ash, containing a relatively low amount of acid-soluble components (42 per cent. soluble ash on total ash), and a low amount of total bases, imply a high silica content of leaf material, such as might be expected of trees growing in decomposing volcanic rock. Whether or no the uptake of silica exerts a disturbing influence on mineral nutrition cannot be decided without further investigation.

(VII) Grenada ; Estate Conditions.

The peculiar features shown by the analytical data for scorched leaves obtained in Tobago are also shown by the data for Grenada, namely an exceptionally high total ash content, a low soluble ash content (only 34 per cent. of total ash), and a low content of total bases. Nitrogen, phosphate and potash contents of scorched leaves are all very low, and nitrogen-potash ratio is extremely high. Evidently the conditions favouring leaf-scorch in soils directly derived from volcanic rocks are peculiar and somewhat different from those obtaining in other types of cacao soil. Leaves showing little or no scorch in Grenada differ in composition from those showing severe scorch, in a manner similar to that shown by contrasted cases in Trinidad.

General Conclusions.—Averaged data for severely-scorched cacao leaves and slightly or not scorched leaves are presented at the foot of Table III. The main analytical features differentiating scorched from unscorched leaves are (1) a higher nitrogen-potash ratio (usually numerically greater than 1.0), (2) a lower potash-lime ratio (usually much less than 1.0), (3) a relatively higher total ash content of dry matter

(generally greater than 10 per cent.), (4) lower (about 70 per cent.) soluble ash and lower (about 80 per cent.) total base contents of ash, (5) relatively much lower gross contents of nitrogen and potash, while gross lime and magnesia contents are nearly identical.

These features of the scorched cacao leaf are believed to be an expression of the premature disorganisation of the protoplasmic linings of the foliar cells. This enhances water-loss, which proceeds inwards from the apical periphery. Unbalanced mineral nutrition, particularly in respect to nitrogen, potash and lime contents of the leaf, is suggested as the cause of the premature senescence, but its relationship to soil composition is obscure except in-so-far as low available potash content, high degree of acidity and marked lime deficiency, as well as high content of nitrogenous organic matter having low carbon-nitrogen ratio, may all be conducive to the lack of balance. The possible effect on these complex relationships of soil moisture conditions, involving rainfall, shading, drainage and soil aeration, remains yet to be investigated.

Note on Thrips.

THE POSSIBLE RELATIONSHIP BETWEEN LIABILITY OF CACAO TO THRIPS ATTACK AND LEAF-SCORCH.

The most destructive pest of cacao in Trinidad is Thrips (*Heliothrips rubrocincta*), a leaf-sucking insect whose depredations are frequently responsible for low yields. Thrips attacks generally occur towards the end of the wet season (October and November), and appear definitely to be associated with pronounced changes in weather conditions.

During the progress of our detailed ecological studies of cacao growing in contrasted "good" and "bad" environments, McDonald noted that Thrips attacks developed in both plots *whenever available soil moisture content fell rapidly while atmospheric humidity remained at a high level.**

* *Second Annual Report on Cacao Research*, 1932; Chemical and Ecological Section, p. *iii*.

During these periods, flowers were forming and fruits were setting, but a temporary cessation in the rainfall allowed the soil to dry out somewhat, so that the conditions favoured a partial desiccation of the leaves and a shedding of the young pods. This tendency to water-loss appears to have been *greatly enhanced by a low potash content of the leaves and a high nitrogen-potash ratio*, such as are also characteristic of cacao affected by severe scorch (*See* Table V).

The evidence thus supports the view that Thrips are able to attack cacao leaves only during periods of partial internal desiccation while the high atmospheric humidity is favourable to the multiplication of the insect. The constant association in the field of leaf-scorch with Thrips damage further strengthens this view. Presumably, any factors which operate to produce temporary leaf desiccation during phases of moisture fluctuations in the environment of the cacao tree will favour Thrips attack, as well as a tendency towards the development of leaf-scorch. Only when the desiccation is so profound, however, that the damage to the peripheral leaf tissues is permanent and irreversible would leaf-scorch be expected to show. Such violent moisture fluctuations are associated with unsuitable environments (for example the "bad" plot as contrasted with the "good"), and a low available potash content of soil seems to be an important attribute of a bad cacao environment.

Agricultural Relationships.

Since leaf-scorch seems to be caused by premature tissue desiccation, resulting from protoplasmic disorganisation, apparently induced by internal potassium deficiency, any environmental factors that restrict the uptake of water by the plant, or favour rapid evaporation from the foliage, should augment its development. Thus, in the case of leaf-scorch of fruit trees in England, Wallace has shown that (apart from an unsatisfactory potash status) soils carrying scorched trees exhibit textural features conducive to "physiological drought".

Table V.

CHEMICAL COMPOSITION OF ASH OF HEALTHY CACAO LEAVES AND LEAVES INFESTED BY THRIPS.

Condition of Mature Leaf.	Water in Fresh Leaf Per cent.	Total Ash in Dry Matter Per cent.	Composition of Ash.			Ratios.		
			Nitrogen N	Phosphate P_2O_5	Potash K_2O	N/P_2O_5	N/K_2O	K_2O/P_2O_5
			Per cent. Ash.					
Very Good—healthy	66.6	9.9	23.7	5.0	26.7	4.7	0.89	5.3
Good—healthy	61.2	12.3	19.0	2.7	15.1	7.7	1.26	5.6
Bad—healthy	61.6	12.3	19.9	2.5	14.2	8.0	1.42	5.7
Bad—Thrips	**57.8**	**14.2**	**14.9**	**2.5**	**7.5**	**6.0**	**1.96**	**3.0**
FOR COMPARISON								
Scorched .... (Means of all)	—	**13.2**	**14.8**	**2.5**	**8.4**	**6.0**	**1.82**	**2.6**

The soils of " scorched " areas in England have been classified by Wallace into (1) light sandy soils having low water-holding capacity, (2) compact shallow silty soils underlaid by impervious subsoils, (3) heavy clay soils having poor drainage. Similar types of soil occur in many of the cacao lands of Trinidad where leaf-scorch abounds ; for example, the open sandy soils of River Estate ; the shallow sandy soils of the hillslopes of the Toco District and of the hillcrests of the Sangre Grande-Manzanilla District ; the poorly-drained compact silty soils of the northern river vegas, and certain of the heavy clay soils of the Naparima District. Furthermore, exposure to drying winds and inadequate overhead shade may intensify foliar desiccation, so that leaf-scorch tends to be more prevalent in poorly-protected sites ; the " sea-blast " theory is thus justified, but only in so far as it may be applied to areas having unsatisfactory physical and chemical soil conditions.

Wih regard to the probem of rectifying leaf-scorch in fruit trees already established in orchards, Wallace has stressed the fact that a considerable period of time may elapse before corrective treatments begin to exert any noticeable effect. Thus, potash manuring may not at once remove leaf-scorch when applied to soils having high potassium-absorbing capacity, or containing considerable amounts of available calcium and magnesium. In his field experiments, relief from scorch was seldom obtained in less than three years from the time when potash manures were first applied. Grassing-down sometimes helped recovery by suppressing excessive uptake of nitrogen. Orchard weeds thus have their uses, in that they temporarily fix superfluous nitrogen, and this effect may be particularly important at the beginning of wet seasons in cacao cultivations where nitrate production rapidly increases during dry weather. Manuring with soluble nitrogenous compounds should obviously not be attempted in cases of leaf-scorch, although phosphate manuring, where the soil is deficient in phosphate, might aid recovery by enhancing the plant's ability to absorb potassium through greater root growth. Heavy fruiting is stated by Wallace to be conducive to scorching, while certain varieties of fruit trees are more susceptible than others.

The most perplexing problem of all in established fruit orchards is the amelioration of soil conditions, especially in lands that have been allowed to deteriorate through neglect. It is notoriously difficult to restore a suitable soil structure necessary for satisfactory aeration and water movement in soil that has become compacted and waterlogged. The mere opening of surface drains may fail to draw the water out of impervious clays ; tillage is generally harmful in that it may seriously injure the active root system, and ground limestone is ineffective if applied to the soil surface without proper incorporation, although the judicious application of *soluble* calcium compounds, such as slaked lime (calcium hydroxide), calcium superphosphate, nitrate of lime (calcium nitrate) or even calcium chloride, may hasten the beneficial cycle of changes because of their greater soil penetration. Perhaps the most satisfactory means of eventually improving soil structure in deteriorated orchards is to encourage the growth and multiplication of herbaceous shade plants, whose roots deeply penetrate and ramify in the soil. The rootlets break up the hardened soil mass and produce a stable crumb structure ; their decayed residues gradually increase the soil's content of organic matter which increases the percolation of water and air. Correct manuring with artificial manures encourages weed growth as well as the production of foliage on the trees, and this tends further to increase the amount of organic matter through leaf shedding ; periodic cutting-back of the weeds would prevent undue competition with the crop, and would augment their growth, but clean-weeding should not be attempted. It is nevertheless doubtful whether a beneficial cycle of changes can ever be inaugurated economically in lands that have become subject to surface erosion and have already lost their natural humic covering.

Summary.

(1) Marginal leaf-scorch of cacao, widespread in Trinidad, Tobago and Grenada, is the result of an unsatisfactory soil and atmospheric environment.

(2) The chief soil feature is a deficiency of available potash, or some condition that causes a lack of " nutritional balance ", especially with regards to the uptake of potassium, calcium and nitrogen by the cacao tree.

(3) Contributing factors are (*a*) an unsatisfactory soil structure, which adversely affects the water relations of the soil, and (*b*) atmospheric exposure, which is conducive to desiccation of soil and plant.

(4) Evidence supporting these conclusions has been adduced from sand culture experiments on cacao seedlings and cuttings, from soil survey and manurial investigations involving laboratory soil examination, and from chemical analysis of leaf material.

(5) Provisional limits for available potash content of soil supporting healthy cacao trees free from leaf-scorch have been established for different textural types ; the limiting values range from 100 to 175 p.p.m. exchangeable potash.

(6) The chief analytical features differentiating cacao leaves liable to scorch from healthy leaves are (*a*) a high nitrogen-potash ratio (*b*) a low potash-lime ratio, (*c*) a high total ash content, (*d*) a low soluble ash and total base content, and (*e*) a low gross content of nitrogen and potash.

(7) The conditions favouring attack by Cacao Thrips appear to be similar to those conducive to leaf-scorch. In each case, unsatisfactory environmental conditions cause pronounced leaf desiccation, which may be only temporary in the case of susceptibility to Thrips, but permanent in the case of leaf-scorch.

(8) Amelioration of leaf-scorch may be expected from suitable manuring, mainly with potash salts, but the "cure" may require successive applications for more than two or three years.

(9) Improvement of soil structure in established cacao fields may be difficult to accomplish, particularly where deterioration through neglect has occurred, resulting in the loss of humic surface soil. The problems of drainage, tillage, liming and manuring are briefly considered; the judicious encouragement of natural herbaceous weed growth is recommended as the most promising procedure.

(3) MANURIAL EXPERIMENTS ON CACAO IN TRINIDAD: 1932-1936.

By F. Hardy.

The following account comprises a summary of three-and-a-half years' experimental work, undertaken by the officer of the Chemical Section of Cacao Research (J. A. McDonald), together with a discussion of further results obtained by officers of the Trinidad Department of Agriculture Cacao Relief Scheme, who took over the work in January, 1936. The writer is indebted to Dr. F. J. Pound, Agronomist of the Trinidad Department of Agriculture, and formerly officer of the Botanical Section of Cacao Research, for information regarding the results obtained in 1936.

(I) Introductory.

The series of specific manurial experiments on cacao in Trinidad, initiated under the Cacao Research Scheme, was started during the three-months' period May-August, 1932, when seven phosphate experiments were laid down as an outcome of the important discovery that many of the cacao soil-types occurring in Trinidad and Grenada are very deficient in available phosphate as estimated by the Truog chemical test.

The soils on which the phosphate manurial experiments were laid down comprise the following types:—

	Designation of Experiment.
(A) Alluvia Soils.	
(1) Acidic clay, Recent River Alluvium; Las Hermanas Estate, San Rafael, Northern Plain	Las Hermanas I.
(2) Slightly acidic loamy sand, Recent River Alluvium; Torrecilla Estate, Arima, Northern Range (Centre)	Torrecilla.
(3) Acidic loamy-silt, Recent River Alluvium, River Estate, Diego Martin, Northern Range (West)	River Estate I.
(B) Sedentary Soils.	
(4) Acidic clayey silt, derived from highly gypseous Brasso Clay, Sta. Serviera Estate, Central Range	Sta. Serviera.
(5) Neutral black clay, derived from Princes Town Marl Bajan's holding, Ecclesville near Rio Claro, Southern Plain	Rio Claro I.
(6) Highly acidic clay derived from gypseous Green Clay, Bajan's holding, Ecclesville, near Rio Claro, Southern Plain	Rio Claro II.
(7) Alluvial clay-loam, Red Earth derived from augite andesite igneous rock, Carriere Estate, Grenada....	Grenada.

(II) Results of the Initial Manurial Experiments.

(1) The *Las Hermanas I* experiment is still being continued. Yield results are now available for four consecutive years (1933 to 1936). In 1934, sulphate of potash was applied as a half-plot treatment at the rate of two lb. per tree. There are 16 plots arranged in a 4 by 4 Latin square. Each plot contains 18 trees of initial average age 32 years. Conclusions derived from this experiment are discussed below.

(2) The *Torrecilla* experiment was discontinued after two years' (1933, 1934) yield data had been obtained. Superphosphate manure, applied at the rate of two lb. per tree, gave a significant 38 per cent. increase in yield of wet cacao beans, which was profitable at current low prices. The loamy-sand soil was very deficient in available phosphate (only 21 p.p.m., Truog's test). A superimposed half-plot treatment with potash manure, applied in 1933, gave no additional significant increase in yield. The layout resembled the last; the trees were aged 55 years.

(3) The *River Estate I* experiment was discontinued after two years' (1933, 1934) yield data had been collected. Superphosphate manure, applied at the rates of 1½ and 3 lb. per tree, gave significant increases in yield of 41 and 35 per cent. respectively. The first was probably profitable. The loamy-silt soil was very deficient in available phosphate (15 p.p.m.), and also very deficient in available potash (only 56 p.p.m. exchangeable potash). No potash treatment was applied, however, in this experiment.

(4) The *Sta. Serviera* experiment on highly gypseous Brasso Clay soil was discontinued (because of a severe land-slip which affected some of the plots), after two years' (1933, 1934) yield data had been obtained. Superphosphate gave no significant increase in yield, presumably because

of the interference or deleterious effect of gypsum occurring naturally in this soil-type, even though the soil was deficient in available phosphate (29 p.p.m.). A superimposed half-plot potash treatment, applied in 1933, also gave no appreciable yield increase. The general yield of cacao was very low in all the plots. The layout was a 4 by 4 Latin square, 18 trees to the plot; average age, 40 years.

(5) The *Rio Claro I* experiment, on black marl soil, was discontinued in 1935, after yield data for three consecutive years (1933, 1934, 1935) had been collected. Superphosphate was applied in May, 1932, and again in May, 1934. Significant and highly profitable annual increases in yield of *more than* 100 *per cent.* (pods per tree) were obtained by the application of 1½ lb. of superphosphate per tree. The soil contained only 6 p.p.m. available phosphate; a striking characteristic of the Princes Town black marl soil, first revealed by chemical analysis, is its inherently very low content of phosphate. The use of phosphatic manures on this soil type is likely greatly to benefit cacao estates in which it occurs. The layout was a 3 by 3 Latin square; each plot contained 16 trees, of average age 22 years.

(6) The *Rio Claro II* experiment on highly gypseous (Green Clay) soil was discontinued after two years' (1933, 1934) yield data had been collected. Like the Sta. Serviera experiment (No. 4), no significant response to phosphate manure was obtained, even though the soil contained only a very small amount (9 p.p.m.) of available phosphate. Evidently here also, natural soil gypsum appears to prevent the cacao tree from benefitting by phosphate manuring. Except for this harmful factor, the other attributes of both the Brasso Clay gypseous soil (Sta. Serviera) and of the Green Clay gypseous soil (Rio Claro II), as revealed by chemical soil examination in the laboratory, appear to be satisfactory. The mode of action of gypsum in preventing phosphate utilisation has not yet been fully elucidated, although evidence has been obtained that low contents of both available iron and manganese in the soil may be involved in the relationship.

The Rio Claro II experiment comprised two 3 by 3 Latin squares, each plot containing 16 trees, of average age 22 years. Actually both the Rio Claro experiments (I and II) were initiated by officers of the Trinidad Department of Agriculture, who were responsible for the recording of yield data. By a peculiar coincidence, one Latin square out of the three originally laid down on Bajan's land occurred on black marl soil, and the other two on Green clay gypseous soil, the sharp boundary between the two soil-types crossing the experimental area. This fact was not discovered until a detailed soil survey by auguring was made, and the soils subsequently examined in 6-foot profile pits dug at three places within the area. The peculiar case of the two Rio Claro experiments demonstrates *the importance of the detailed soil survey as a prerequisite to the laying-down of manurial experiments in the field.* The soil survey, whenever possible, should precede the selection of sites for manurial experiments.

(7) The *Grenada* experiment on red earth volcanic soil was discontinued after two years' (1933, 1934) yield records had been collected, because the original lay-out proved not to be satisfactory. The records indicated that some increase in yield of cacao (about 17 per cent.) was obtained by phosphate manuring on red earth soil.

Other cacao manurial experiments on different soil-types (including red earth) are to be inaugurated by Dr. F. J. Pound in Grenada in the near future.

Summary.—Out of the seven phosphate manurial experiments laid down in Trinidad and Grenada during 1932, only one (namely, Las Hermanas (1), was continued during the past year (1936); this experiment is still being continued by officers of the Trinidad Department of Agriculture, under the auspices of the Cacao Relief Scheme. The results obtained to date are considered in detail below.

(III) Further Manurial Experiments.

Two new series of manurial experiments on cacao in Trinidad were inaugurated during 1934 and 1935. Experiments included in the first of these new series were designed mainly to test the comparative value of different types of phosphatic manures on phosphate-deficient soils, *while* those included in the second of the new series are general manurial experiments, involving trials of nitrogenous, phosphatic and potassic manures, applied both singly and in various combinations. These further manurial experiments may be designated as follows:—

(A) Phosphate Series.

(8) *Las Hermanas II* Same soil-type as Las Hermanas I; acidic river alluvial clay.
(9) *Las Hermanas III* Ditto.
(10) *Rio Claro III* ....Same soil-type as Rio Claro I; black marl soil.

(B) General Manures Series.

(11) *River Estate II* ....Same soil-type as River Estate I; acidic river alluvial loamy-silt (Shaded cacao).
(12) *River Estate III* .... Ditto (No shade).
(13) *River Estate IV* .... Ditto. (Mulch).
(14) *River Estate V* .... Ditto. (Potash types).
(15) *Rio Claro IV* ....Same soil-type as Rio Claro I and III: black marl soil. (Gypsum effect).

In addition to the five general manurial experiments listed above, a large-scale experiment, designed and laid down in May, 1933, by

F. J. Pound and J. de Verteuil at River Estate, is included in the discussion that follows. It may be designated (16) *River Estate V I.* This experiment was fully described in the Third, Fourth and Fifth Annual Reports on Cacao Research (for the years 1933, 1934 and 1935), under the general heading " Studies of Fruitfulness in Cacao ", Parts IV, VI and VIII, contained in the Botanical Section of these reports, at pages 28-32 ; 19-25, and 16-19, respectively.

(IV) Description and Results of Manurial Experiments on Cacao for which data were obtained during the year under review (1936).

The following experiments, now in being, have given results during the past year, which may next be considered in their further bearing on manurial problems of cacao growing in different soil-types representative of the cacao lands of Trinidad.

(A) PHOSPHATE SERIES.

(i) Las Hermanas I (1). 1932-1936. Field, Santa Rita.

Object.—This experiment was designed to test the effect of applications of superphosphate manure both alone and together with sulphate of potash manure applied in half-plot treatments, on cacao growing in acidic alluvial clay soil, such as occurs in the " vegas " or riverain strips of the Northern Plain of Trinidad. Superphosphate here has been applied annually four times since 1932, at the rates of 1, 2 and 3 lb. per tree, and sulphate of potash twice since 1934, at the rate of 2 lb. per tree. The total yields and percentage increases in yield are set out in Table I.

Conclusions.—(1) The average annual percentage increases in yield given by the three dressings (3 lb., 2 lb. and 1 lb.) of superphosphate, over the whole period of the experiment, were 73.2, 33.5 and 45.5 per cent. respectively.

(2) The continued application of the two heavier dressings appears to have been excessive, yield responses having diminished greatly for the last applications made in 1935.

(3) The most economical dressing of superphosphate has been 1 lb. per tree per annum, whilst the larger dressings of 2 lb. and 3 lb. were not economical.

(4) The profits gained by the 1 lb. dressing would be $2.71, $4.90 and $7.08 per acre per annum when the prices of cacao are respectively six cents, eight cents and ten cents per pound, exclusive of the cost of preparing the cacao.

(5) The application of potash gave no profitable increases in yield in this experiment ; the potash yield results have not been included in the table.

(ii) Las Hermanas II (8). 1935-1936. Field, San Pedro.

Object.—To compare ground rock phosphate with superphosphate, and to test the further effect of superimposed potash on these treatments, on cacao growing in acidic river alluvial clay soil.

The experiment comprises a 5 × 5 Latin square, each plot carrying 18 trees of average age 32 years. Potash was applied as half-plot treatments of 1½ lb. of sulphate of potash per tree. Yield data are given in Table II.

Conclusions.—(1) The average annual percentage increase for all plots treated with superphosphate was 62 per cent., and for all plots treated with ground rock phosphate, 48 per cent. Evidently superphosphate gives the larger increases in yield, both with and without potash.

(2) Superphosphate gave an increase in yield equivalent to about ¾ bag (124 lb.) of dry cacao per acre, the manure costing $8.00 per acre. When the value of dry cacao is six cents per lb., the value of this increase per acre is $7.44, so that the manuring is evidently not profitable. At ten cents per lb., the profit would be $4.40 per acre.

Table I.

Las Hermanas I.

Effect of Superphosphate on Cacao Growing in Acidic Alluvial Clay Soil.

Annual Dressing of Superphosphate Manure.	Percentage Increases in Yield of Wet Cacao Beans.				Total Yield per 72 Trees (lb. Wet Cacao).	Total Increase in yield over Control (lb Dry Cacao).	Value of Increased yield at 6c. lb.	Cost of Manure.
							$ c.	$ c.
	1933.	**1934.**	**1935.**	**1936.**				
3 lb.	78.3%	141.5%	61.7%	11.4%	989	152.4	9.14	11.52
2 lb.	41.2	59.8	25.7	7.4	787	71.6	4.30	7.68
1 lb.	46.3	48.8	54.9	31.8	881	109.2	6.55	3.84
Control	—	—	—	—	608	—	—	—
Total Yields per 72 Trees	990	533	949	793	3,265	—	—	—
Yield per tree	13.8	7.4	13.2	11.0	—	—	—	—

Table II.

Las Hermanas II.

COMPARISON OF SUPERPHOSPHATE AND GROUND ROCK PHOSPHATE WITH AND WITHOUT POTASH ON CACAO GROWING IN ACIDIC ALLUVIAL CLAY SOIL.

Annual Dressing	Natural Yield before Manuring	Increases over Natural Yields	Increases over Natural Yields	Average Annual Increases	Percentage Increases over Control.
	(Lb. weight of wet cacao bears.)				
	1934.	**1935.**	**1936.**		
2 lb. Superphosphate	77	222	76	149	52%
do. do. +1½ lb. Potash	69	240	79	160	72
3 lb. Rock Phosphate	77	186	71	129	38
2 lb. do. +1½ lb. Potash	82	237	99	168	58
Control	90	139	29	84	—
Total Yields per 90 Trees	395	1,419	1,773	—	—
Yield per Tree	4.4	15.8	19.7	—	—

(3) When potash was applied along with phosphate manure, the increase was 1⅛ bags (186 lb.) of dry cacao per acre, for an outlay of $22.00, which again is not profitable when cacao is valued at six cents per lb., nor when it is ten cents per lb.

(4) There is apparently some factor or factors other than phosphate and potash limiting cacao production in the particular type of soil represented at this experimental site, since, even when manures are used, the general level of productivity is still very low. The soil conditions are being further investigated. Soil acidity may be excessive, or exchangeable calcium may be deficient; the soil may require thorough draining. Field experiments designed to test the effects of liming and draining, and of applications of nitrogenous manure, in addition to phosphate and potash, are being contemplated for this site.

(iii) Las Hermanas III (9). 1936. Field, Maria Sambrano.

Object.—To compare ground rock phosphate, "Nicifos A", and double superphosphate with superphosphate, and to test the further effect of superimposed potash, on cacao growing in acidic river alluvial clay soil.

The experiment comprises a 5 by 5 Latin square, each plot having 22 trees of average age 32 years. Potash was applied in half-plot treatments of 1½ lb. sulphate of potash per tree. Yield data are given in Table III.

Table III.

Las Hermanas III.

COMPARISON OF DIFFERENT KINDS OF PHOSPHATIC MANURES WITH AND WITHOUT POTASH ON CACAO GROWING IN ACIDIC ALLUVIAL CLAY SOIL.

	Yield, lb. Wet Cacao 1936.	Percentage Increase over Control.
3 lb. Superphosphate ..	298	31.9
3 lb. Rock phosphate ..	253	11.9
1¾ lb. "Nicifos A" ..	290	28.3
1½ lb. Double Super ..	306	35.4
Control	226	—
Total Yields per 110 trees	1,373	—
Yield per Tree	12.5	—

Conclusions.—(1) In this experiment also, superphosphate (as well as the two other *soluble* phosphatic manures, namely "Nicifos" and double superphosphate) have given greater increases in yield in the year following the application than the less readily available ground rock phosphate, but the percentage increases in yield were only about half as great for superphosphate as in the last experiment. Greater increases may occur in subsequent years following further additions of manure.

(2) Double superphosphate, applied at half the rate of superphosphate, gave approximately the same percentage increase in yield.

(3) " Nicifos A ", applied also at half the rate of superphosphate, was less effective, probably because of the depressing action of its nitrogen content on soil already containing abundant nitrogen.

(4) Potassic manure gave no significant additional increases in yield in this experiment, a result (untabulated) which agrees with that of Experiment (I), but not with that of Experiment (II). Evidently great variability may occur in soils belonging to the same type (acidic alluvial clay soil).

(iv) Rio Claro III (10). 1936. Jackson Field, Poole Syndicate.

Object.—To compare three different kinds of soluble phosphatic manure and ground rock phosphate, and to test the further effect of potassic manure (muriate of potash) on cacao growing in black marl soil.

The experiment comprises two 5 × 5 Latin squares, each plot containing 22 trees of average age 22 years. Yield data for the first year are presented in Table IV.

Table IV.

Rio Claro III.

Comparison of Different Kinds of Phosphatic Manures with and without Potash on Cacao Growing in Black Marl Soil.

	Yield Bags Dry Cacao, per 1,000 Trees.			Percentage Increase over Control.
	Latin Square A.	Latin Square B.	Mean (Bags /1000)	
3 lb. Superphosphate....	16.5	16.1	16.3	74.1
3 lb. Rock phosphate....	9.3	11.5	10.4	11.2
1¾ lb. " Nicifos A "	12.2	13.1	12.6	35.3
1½ lb. Double Superphosphate	14.2	12.1	13.1	40.6
Control	11.0	7.7	9.3	—

Conclusions.—(1) The superphosphate plots gave seven bags of dry cacao per 1,000 trees more than the control plots. The trees are 14 feet apart, so that 1,000 trees occupy nearly 4½ acres of land. The cost of the manure per 1,000 trees was $40; hence an increased yield of just over 1½ bags of dry cacao per acre was obtained for an expenditure of $10. With cacao selling at six cents per pound, the value of this increased yield is $15.25, and the profit nearly $5 per acre. At ten cents per pound, the profit would be $15.40 per acre, which is very remunerative, though exclusive of the extra cost of carting, fermenting and drying the additional crop.

(2) Rock phosphate produced only a slight increase in yield, which was unprofitable. Presumably this slower acting manure may show greater benefit later.

(3) " Nicifos A " and double superphosphate gave profitable returns, but " Nicifos A "* proved less effective than the other soluble manures, probably chiefly because of the depressing effect of its nitrogen content on a soil initially rich in nitrogen.

(4) Potash manure (muriate of potash; potassium chloride) applied in half-plot treatments, gave no additional response. The black marl soil is notably well supplied with potash as revealed by chemical tests (between 200 and 300 p.p.m. of exchangeable potash), so that this result was not unexpected.

(5) The yield of the unmanured (control) plots of 9.35 bags of dry cacao per 1000 trees is high for this soil-type, and is partly explained by the fact that only good trees were included in the experiment. This preliminary selection eliminated some 20 per cent. of the tree population within the experimental area. Hence the experiment approaches more nearly to the conditions that should ultimately obtain when unproductive or low-bearing trees have been replaced by good bearers, an improvement which is nowadays being gradually effected in many cacao estates in Trinidad. Neighbouring fields on the same black marl soil-type gave only four bags per 1,000 tree-sites or pickets during the period of this experiment, so that evidently enormous improvements in yield may follow the combined practice of replacing poor bearers and of systematically manuring with suitable phosphatic manures on the black marl type of soil which occupies a considerable area of land in the Rio Claro-Princes Town District. Yields in many cases could thus be *more than doubled* within one year of the application and at relatively small cost. The discovery of this fact is the most spectacular result yet obtained in our investigations of cacao soils in Trinidad. The district has recently been surveyed in great detail, and the boundaries of the black marl soil have been accurately delineated.

(B) GENERAL MANURE SERIES.

(v) River Estate II (11). 1934-1936. (Normal Shade), Field 21A.

Object.—To test the effects of nitrogenous, phosphatic and various quantities of potassic manures, applied singly and in combination, on cacao growing in acidic alluvial loamy-silt soil, initially deficient in available phosphate and potash. The experiment comprises a 5 by 5 Latin square, with 22 trees in each plot and average age 22 years. The field carried a normal population of Immortel shade trees.

* " Nicifos " also contains appreciable amounts of sulphate which may be deleterious to cacao.

The nitrogenous manurial dressing was two lb. per tree of ammonium sulphate; the phosphatic, two lb. superphosphate per tree, and the potassic, 1½ lb. sulphate of potash, with a superimposed half-plot treatment of 1½ lb. sulphate of potash per tree. The dressings have been applied annually for two years. Considering half-plots, there are thus nine different treatments, namely (1) N, (2) P, (3) K, (4) NP, (5) NK, (6) PK, (7) NPK, (8) NP2K, (9) no manure.

The results for the two years of this experiment are given in Table V.

Table V.

River Estate II; General Manuring.

COMPARISON ON EFFECTS OF NITROGENOUS, PHOSPHATIC AND POTASSIC MANURES, APPLIED SINGLY AND IN COMBINATION ON CACAO GROWING IN ACIDIC RIVER ALLUVIAL LOAMY-SILT SOIL.

NORMAL SHADE.

Treatments.	Natural Yields previous to the Expt.	Increases in Yield (Lb. Wet Cacao).			Percentage Increases in Yield over Previous Natural Yields.
		1935.	1936.	Average.	
N ..	201	270	138	204	102%
P ..	195	306	185	246	126
K ..	130	375	267	321	247
NP ..	163	393	307	350	215
NK ..	167	363	238	301	180
PK ..	180	436	285	361	200
NPK ..	204	430	259	345	172
NP2K ..	202	521	302	413	206
Control ..	213	223	141	182	85%

Conclusions.—(1) The greatest increase in yield has been given by the *single potash treatment* (K), namely, nearly 250 per cent. of the previous natural yield obtained before manure was applied, which is relatively very great. This increase in yield corresponds to an average increase of 321 lb. of wet cacao beans, or 139 lb. more than the increase in yield of the control (no manure) plot during the 2-years' period of the experiment.

(For statistical significance on a 20 : 1 chance, a difference of about 90 lb. weight is required, so that the increased yield of 139 lb. is evidently highly significant and definitely caused by the addition of potassic manure).

The increase in yield produced by potash manuring alone in this experiment corresponds to 1.84 bags (or 304 lb.) of dry cacao per acre of land.

(2) Nitrogen and Phosphate (NP) gave the next largest increase, but these elements have apparently diminished rather than increased the effects of potash.

(3) Additional potash in the NP2K treatment has given an increase of the same order as nitrogen *plus* potash or phosphate *plus* potash (NK, PK).

(4) It should be particularly noted that these results have been obtained on a loamy-silt soil initially very deficient in available potash and somewhat deficient in available phosphate, though containing abundant nitrogen. They illustrate the sorts of interactions that may occur when such a soil is treated with different mineral manures. Potash seems to be the first requirement, but additional nitrogen and phosphate seem to diminish its effect.

(vi) **River Estate III (12).** 1934-36. (No Shade), Field 20 C.

Object.—The same as the last, excepting that the cacao was *not shaded* by Immortel trees, which were never planted in this area.

The results of this comparable experiment are presented in Table VI.

Table VI.

River Estate III; General Manuring.

COMPARISON OF EFFECTS OF NITROGENOUS, PHOSPHATIC AND POTASSIC MANURES, APPLIED SINGLY AND IN COMBINATION, ON CACAO GROWING IN ACIDIC RIVER ALLUVIAL LOAMY-SILT SOIL.

NO SHADE.

Treatments.	Natural Yields previous to the Experiment.	Increases in Yield (Lb. Wet Cacao)			Percentage Annual Increases in Yield over previous Natural Yields
		1935.	1936.	Annual Average.	
N ..	236	232	204	218	92%
P ..	175	158	174	166	95
K ..	221	248	185	217	98
NP ..	218	154	149	152	70
NK ..	200	279	271	275	138
PK ..	194	276	265	271	139
NPK ..	225	257	238	248	110
NP2K ..	232	367	323	345	149
Control	245	131	150	141	58%

Conclusions.—(1) The greatest increase in yield has been given in this "*No Shade*" experiment by the mixed highly potassic manure (NP2K), namely, nearly 150 per cent. of the previous natural yield, which however is only three-fifths as great as the greatest increase given (by the single potash treatment) in the last ("Normal Shade") experiment.

(2) Nitrogen *plus* potash (NK) and phosphate *plus* potash (PK) have given the next largest increases, but again the effects were less in magnitude (about ¾ as much) than those given by corresponding treatments in the last ("Normal Shade") experiment. Evidently potash is the component most deficient in the soil of both experimental areas.

(3) In general, the most striking result of this experiment is the *smaller effect of manuring cacao under "No Shade" conditions.* It was anticipated that the opposite result would be obtained, in view of the possibility that shade trees might take up much of the manure applied to the cacao trees which ought to suffer in consequence. Actually the reverse result has been obtained for two consecutive seasons at River Estate, although it cannot be concluded that it would occur at any site or in any type of soil. The comparison requires retesting in other established cacao areas.

(vii) River Estate IV (13) 1931-1936. Field 25A.

Object—To test the effect of mulching with vegetable waste matter, applied alone and together with various combinations of nitrogenous, phosphatic and potassic manures, on cacao growing in acidic alluvial loam soil, initially deficient in available phosphate and potash. The experiment comprises a 4 by 4 Latin Square with main treatments of nitrogenous and phosphatic manures, and with half-plot treatments of potash and mulch. Each half-plot contains nine cacao trees.

The nitrogenous manurial dressing was two lb. of ammonium sulphate per tree, the phosphatic, two lb. superphosphate per tree, the potassic, two lb. sulphate of potash per tree, and the mulch dressing, 20 tons per acre. Previous to the application of manures, natural yields were recorded for the years 1932 and 1933. The manures were first applied in 1933, and all except the mulch have been applied every year thereafter. Considering half-plots, there are 15 different treatments, namely, (1) mulch, (2) N, (3) K, (4) P, (5) mulch+P, (6) mulch+K, (7) mulch + P+K, (8) mulch +P+N, (9) mulch+K+N, (10) mulch+P+K+N, (11) mulch+N, (12) P+K, (13) P+K+N, (14) P+N, (15) No manure. The results for this experiment are given in Table VII.

Conclusions.—(1) The greatest responses have been obtained with superphosphate and sulphate of potash applied together, and with the same dressing augmented by mulch.

(2) Mulch with phosphate and mulch with potash have also given large yield increases.

(3) Ammonium sulphate seems to have depressed the beneficial effects of mulch with phosphate and potash, and of phosphate and potash applied without mulch.

(4) Mulch alone has not appreciably affected the yield, but, *in the presence of non-nitrogenous artificial manures, mulch has greatly enhanced their beneficial effects.*

These results are of great importance. Cacao planters in Trinidad have found that organic manures (such as pen manure) are very beneficial, particularly on sandy soils. When pen manure became scarce, ammonium sulphate was frequently employed instead, with the view that it was the nitrogenous component of pen manure that was the effective agent. Results showed, however,

Table VII.

River Estate IV: Mulch Experiment.

Comparison of Effects of Mulch, Nitrogenous, Phosphatic and Potassic Manures, applied Singly and in Combination, on Cacao growing in Acidic River Alluvial Loamy-Silt Soil.

Treatments.	Natural Yields previous to the Expt.	Yields, 1934-5 (lb. Wet Cacao)	Increases or Decreases in Yields over Natural Yields. (lb. wet cacao)	Percentage Increases or Decreases (%)	Difference from Control (%)
Mulch alone	1,386	1,226	−160	−11.6	−3.1
Ammonium Sulphate alone	1,188	1,076	−112	−9.5	−1.0
Potash alone	1,262	1,258	− 4	−0.3	−8.2
Super alone	948	1,019	+ 70	+7.4	+15.9
Mulch+Super	1,672	1,886	+214	+12.8	**+21.3**
Mulch+Potash	1,182	1,407	+225	+19.0	**+27.5**
Mulch+Super+Potash	1,114	1,426	+312	+28.0	**+36.5**
Mulch+Super+Amm. Sulphate	1,275	1,461	+186	+14.6	**+23.1**
Mulch+Potash+Amm. Sulphate	1,259	1,415	+156	+12.4	**+20.9**
Mulch+Super+Pot.+Amm. Sulph	1,494	1,663	+169	+11.3	**+19.8**
Mulch+Ammonium Sulphate	1,832	1,846	+ 14	+ 0.8	+ 9.3
Super+Potash	1,247	1,616	+369	+29.6	**+38.1**
Super+Potash+Amm. Sulphate	1,352	1,459	+107	+ 7.9	**+16.4**
Super+Ammonium Sulphate	1,613	1,573	− 40	− 2.5	+ 6.0
Potash+Ammonium Sulphate	2,072	1,925	−147	− 7.1	+ 1.4
Control (No treatment)	1,682	1,539	−143	− 8.5	—

Values in thick type are statistically significant.

that sulphate of ammonia, applied alone, usually *depressed* the yields of cacao trees, and the conclusion is supported by the results of this experiment. Nevertheless, organic manure, such as vegetable mulch, is evidently of considerable value *when applied together with phosphate and potash*, at least on the particular kind of soil occurring at River Estate. It is possible therefore that the benefit derived from mulch (and pen manure), under these conditions, is accounted for mainly by its carbohydrate content. It has previously been demonstrated that one of the essential features of highly productive cacao soil in Trinidad is a high ratio of carbon to nitrogen, which is believed to favour mycorrhizal activity, and thus possibly to augment the ability of the cacao tree to absorb mineral nutrients.

In order further to test this hypothesis, experiments have recently been initiated in which the possible benefit of *sugar* applied to cacao soils is being tested.

(viii) River Estate V (14). 1936. Field 9A.

Object.—To compare the relative effects of nitrogenous and phosphatic manures, both alone and in combination, on the beneficial effect due to potassic manuring on acidic river alluvial loamy-silt soil, initially deficient in available potash and phosphate.

Table VIII.

River Estate V.

EFFECTS OF NITROGENOUS AND PHOSPHATIC MANURES ON THE BENEFICIAL EFFECTS OF POTASSIC MANURES ON CACAO GROWING IN POTASH DEFICIENT RIVER ALLUVIAL LOAM SOIL.

Treatment.	Yields (lb. wet Cacao).	Means.	Percentage increase over Control.
Ammonium Sulphate.			
plus Sulphate of Potash ..	404	406	9.1%
plus Muriate of Potash	408		
Superphosphate.			
plus Sulphate of Potash ..	485	500	34.4
plus Muriate of Potash	515		
" Nicifos C ".			
plus Sulphate of Potash ..	408	416	11.8
plus Muriate of Potash	424		
Ammonium Sulph. + Super.			
plus Sulphate of Potash	445	436	17.3
plus Muriate of Potash	427		
Sulphate of Potash alone (Control) ..	399	372	—
Muriate of Potash alone (Control) ..	346		

In this experiment, a basic dressing of potassic manure, consisting *either* of sulphate of potash *or* of muriate of potash, was applied in two comparable series of plots. Superimposed on these potash treatments were dressings of (1) ammonium sulphate, 1 lb. 2 oz. per tree, (2) superphosphate, 2 lb. 10 oz. per tree, (3) "Nicifos C", 1½ lb. per tree, and (4) a mixture of ammonium sulphate, 1 lb. 2 oz. and superphosphate, 2 lb. 10 oz. per tree.

The dressing of "Nicifos C" contains both nitrogen and phosphate in amount approximately equivalent to that contained in the mixture of ammonium sulphate and superphosphate. The soil shows marked response to potash manuring, as proved by previous experiments at River Estate.

Only one year's records are available for this experiment, and no precise previous natural yield data were obtained, but the average yield of the experimental block for the 3-year period prior to the application of the manures was 10.23 bags of dry cacao per 1,000 pickets.

Conclusions.—(1) Ammonium sulphate has slightly enhanced the beneficial effect of both kinds of potash manure, but not appreciably.

(2) Superphosphate has greatly enchanced the beneficial effect due to potash, demonstrating the value of phosphate when applied together with potash to this soil-type.

(3) Ammonium sulphate has considerably depressed the effect of superphosphate.

(4) "Nicifos" has not given the same increase in yield as superphosphate, presumably again because its nitrogenous component has diminished the beneficial effect of its phosphate component.

(5) No appreciable difference was shown by the results obtained with the two different kinds of potassic manures. Since muriate of potash is much cheaper than sulphate of potash, this conclusion has particular economic importance. (Thus, had muriate been used instead of sulphate of potash in a later experiment (River Estate VI), the cost of an increase in yield of one bag of dry cacao would have been $5.44 instead of $6.67).

(6) The total yield of the potash-treated block in this experiment was 16.50 bags per 1,000 pickets, which is 6.27 bags per 1,000 more than the average natural yield of the block before the manure was applied, in spite of the fact that the year 1936 was a bad year with respect to climatic influences.

(ix) Rio Claro (15). 1935-1936. March Field, Poole Syndicate.

Object.—To test the presumed deleterious effect of gypsum on the benefit derived from phosphatic manure applied to cacao trees growing on black marl soil.

In this experiment, gypsum (calcium sulphate) was deliberately applied at the rate of six lb. or four lb. per tree, both alone and together with superphosphate manure (four lb. per tree), and tested against double superphosphate (two lb. per tree). Superphosphate itself contains about 60 per cent. of calcium sulphate, but double superphosphate contains none. Hence the experiment should allow a study to be made of the interactions between phosphate and gypsum.

The yield data are given in Table IX. The layout is a 5 × 5 Latin Square.

Table IX.

Rio Claro IV.

Effect of Gypsum on the Beneficial Action of Phosphatic Manure on Cacao growing in Black Marl Soil.

	Contents of Manure.		Yield (Pods per 100 trees).		
	Calcium Phosphate (lb. per tree)	Calcium Sulphate (lb. per tree)	Actual Yields	Increase over Control.	Depressing effect of Gypsum on Benefit due to Phosphate
Superphosphate *plus* Gypsum	1.6	6.4	1,710	+452	23
Superphosphate alone	1.6	2.4	1,726	+468	7
Double Superphosphate alone	2.0	0.0	1,733	+475	—
Gypsum alone	0.0	6.0	1,069	− 189	—
Control	0.0	0.0	1,258	—	—

Conclusions.—(1) The dressing of gypsum depressed the yield of cacao by about 15 per cent.

(2) Double superphosphate alone increased the yield by 37.8 per cent., and superphosphate alone (in spite of its gypsum content, though less phosphate was added), increased the yield by 37.1 per cent.

(3) Superphosphate *plus* additional gypsum increased the yield, in spite of the gypsum, by 35.9 per cent.

(4) It is evident that gypsum depresses, though not greatly, the beneficial effect of phosphate on the yield of cacao growing in alkaline black marl soil.

Unfortunately, no comparable experiments to test the effect of gypsum on response to phosphate on *acidic* (non-calcareous) soil have yet been laid down in Trinidad, but it is surmised that much greater depressing effects would be realised in this case, since most of the naturally-gypseous cacao soils in Trinidad are acidic, and contain no free lime in the surface layers. It is therefore possible that superphosphate may *not* be the best kind of phosphatic manure to apply, especially to acidic cacao soils, because this type of manure contains considerable amounts of gypsum (as calcium sulphate). Indeed, previous experiments (e.g. Las Hermanas III) have shown that double superphosphate (which contains no calcium sulphate) gives greater yield increments than (single) superphosphate on acidic clay soil. In view of this fact, it is thought that high-grade *Basic Slag* may be a suitable kind of phosphatic manure for acidic cacao soils, because it contains appreciable amounts of lime in addition to easily-available phosphate, and its cost is relatively low. Accordingly, basic slag is to be tested in the immediate future. Rock phosphate also usually contains small amounts of free lime, but its phosphate content may not be so quickly available as that of basic slag, and it certainly is not so readily available as that of superphosphate, as has repeatedly been demonstrated. Comparisons of different kinds of phosphatic manures deserve continued testing with regard to their effects on cacao production.

(x) River Estate VI (16). 1934-1936. Field 8A.

Object.—To test further the effects of nitrogenous, phosphatic and potassic manures, applied singly and in combination, on normally shaded cacao growing in acidic alluvial sandy-loam soil, initially deficient in available potash.

This elaborate large-scale experiment, first initiated by the Botanical Section of Cacao Research, has now given results for three consecutive years. The lay-out is a 4 by 4 Latin Square, with superimposed half-plot treatments. The cacao trees were 30 years old.

The manures applied were ammonium sulphate in rather large dressings (four lb. per tree), superphosphate (two lb.) and sulphate of potash (two lb.). Records of natural yields obtained in 1931-1932 were used for purposes of checking. A striking feature of the experiment is that the yield of the control (no manure) plots has steadily diminished, especially in 1936, which was considered to be a particularly bad year as regards climate. All the manured plots *except* those treated with potash or potash *plus* phosphate, have also shown diminished yields. The actual yield records are presented in Table X. Further details may be obtained by reference to the articles by F. J. Pound and J. de Verteuil published in the 3rd, 4th and 5th Annual Reports on Cacao Research.

Table X.

River Estate VI: General Manuring.

Comparison of Effects of Nitrogenous, Phosphatic and Potassic Manures applied Singly and in Combination, on Cacao growing in Acidic River Alluvial Sandy-Loam Soil.

FULL SHADE.

	Natural Yields previous to the Expt.	Increases in Yield (No. of Pods per 100 Trees)			Annual Average	Percentage Annual Increases in Yield over previous Natural Yields (Averages).	Percentage Annual Increases due to Manures (Averages).
		1934	1935	1936			
N	1,160	−336	− 9	−577	−301	−26.0%	—
P	952	− 85	−112	−282	−160	−16.8	—
K	912	+ 24	+470	+107	+200	+21.9	47.5%
NP	856	−184	−205	−332	−240	−28.0	—
NK	1,136	−112	+ 62	−288	−113	−10.0	—
PK	1,168	+176	+605	+114	+298	+25.5	51.8
NPK	984	+128	+418	+ 93	+213	+21.6	47.0
Control	1,016	− 96	− 94	−337	−176	−17.3	—

Conclusions.—(1) Ammonium sulphate, whether applied alone or in combination with other manures, has given diminished yields as compared with no manure.

(2) Superphosphate alone has apparently produced a 16.8 per cent. decrease in crop yield as compared with the natural decline of 17.3 per cent. for the unmanured plots, but when applied with sulphate of potash, or with ammonium sulphate and sulphate of potash, the yield has been greatly increased (by nearly 50 per cent.) over the yield of the control plots.

(3) Sulphate of potash is obviously the most valuable of the three kinds of manures for increasing crop production on this soil-type, and its effect is somewhat enhanced when phosphate is supplied in addition. Whilst the control plots decreased naturally in yield by about 17.3 per cent. (*i.e.* they maintained an 82.7 per cent. yield level), the plots treated with potash maintained a mean level of 123.0 per cent.

(4) Detailed costings showed that in this experiment the expenditure on potash manure required to produce *each bag increase* of dry cacao was $6.67, which would show a profit of $3.23 per bag when cacao is worth six cents per pound or of $9.83 when it is worth ten cents per pound, exclusive of the extra cost of reaping, carting and preparing the additional cacao obtained.

Summary.

(1) The manurial experiments (15 in number) described in this article have clearly revealed the nutrient requirements of three distinctive types of cacao soil occurring widespread in Trinidad, namely:—

(i) Acidic River Alluvial Clay Soil, Northern Plain, (ii) Acidic River Alluvial Sandy Soil, Northern Range Valleys, (iii) Neutral Marl Black Clay Soil, Southern Plain. Chemical tests have shown that each of these three soil-types is usually very deficient in available phosphate, whilst the second is also usually deficient in available potash.

(2) The manurial experiments have been designed chiefly to test:—

(i) interactions between phosphatic and potassic manures, (ii) relative value of different kinds of phosphatic manures, (iii) profitableness of artificial manuring at current prices of cacao, (iv) effects of nitrogenous manure (ammonium sulphate chiefly), on benefits derived from phosphatic and potassic manures, (v) depressing effects of gypsum on manurial benefits, (vi) relative effects of shade and no shade on manurial benefits, (vii) effect of mulch on manurial benefits, (viii) relative value of sulphate and muriate of potash.

(3) In general, exceptionally large responses have been obtained by suitable artificial manuring, for example:—

(i) *Acidic Alluvial Clay.*—Highly profitable increases in cacao yields were obtained in one year by small dressings of superphosphate and of other soluble phosphatic manures, but not by larger dressings, nor so far by insoluble rock phosphate. Potassic manure sometimes gives further small increases, which are generally not profitable when cacao prices are low. Nitrogenous manure depressed yields. Soil acidity may be restricting manurial responses; liming is to be tested. Unsuitable soil texture and lack of aeration may be

depressing factors; the effects of draining are to be examined. Basic slag is to be tested against other phosphatic manures.

(ii) *Acidic Alluvial Sand.*—Highly profitable increases were obtained with potassic manures alone. Muriate proved to be as effective as the more expensive sulphate of potash. Benefit due to potash is usually enhanced by phosphate, but diminished by nitrogen. Phosphate used alone proved beneficial, but its effect is greatly enhanced by potash. In one experiment (River Estate), manures applied to a field carrying no shade trees gave less response than manures applied to a normally shaded field. Vegetable mulch applied alone depressed the yields, but applied with potash and phosphate it greatly increased the yields, presumably because of its carbohydrate content. Nitrogenous manure usually diminished the benefits derived from potash and phosphate; applied alone it gave no response.

(iii) *Neutral Black Marl Soil.* — Highly profitable increases (over 100 per cent.) were obtained with small dressings of superphosphate and of other soluble phosphatic manures, but not so far by insoluble rock phosphate. Potassic manures gave no beneficial effects. Nitrogenous manure depressed the yields slightly, but it may be beneficial when the phosphate and potash status has been improved. Gypsum (calcium sulphate), deliberately added, depressed the yields, and slightly diminished the benefit from phosphate manure. It may be even more deleterious in highly acidic cacao clay soils.

Future Manurial Investigations.

Most of the experiments described in this article will be continued in future years, and additional experiments, based on their results, will be inaugurated to test important conclusions. These investigations will be maintained under the charge of officers of the Trinidad Department of Agriculture (Cacao Relief Scheme).

A large number of such additional manurial experiments have already been designed and laid down under the direction of Dr. F. J. Pound, during 1936. They are classified into four types, namely (1) Latin Square, "A" type of field experiments, similar to those described in this article, (2) Acre Block, "B" type, whose results are amenable to computation on the Latin Square plan, (3) Special experiments, designed chiefly to test Witchbroom effects, cultivation methods, pruning and budding, (4) Estate manuring and cacao rehabilitation experiments, based on records provided by planters from fields that have been manured, or whose tree populations have been improved by pruning and replanting, and by soil cultivation and draining.

At the end of 1936, 35 Type "A" experiments were in being (including the 15 described in this article), together with some 160 Type "B" acre-block experiments distributed over cacao estates in Trinidad and Tobago. The number of experiments will be considerably increased during 1937, so that precise information will gradually become available regarding the best methods of manuring cacao lands occurring on the main soil types of the Colony. At the same time, the detailed soil survey of Trinidad, commenced in May, 1936, by Dr. E. M. Chenery, Government Soil Surveyor, is being rapidly extended, so that, in due course, the manuring and field treatment of the cacao crop in Trinidad and Tobago will be placed on a sound basis.

PART II.—THE BIOCHEMISTRY OF CACAO.

(1) A PRELIMINARY INVESTIGATION OF THE BIOCHEMICAL ATTRIBUTES OF QUALITY IN FRESH CACAO BEANS.

By J. A. McDonald.
(*Formerly Chemist for Cacao Research*).

There are three main botanical varieties from which the cacao beans of commerce are produced namely:—

(1) *Criollo,* which yields cocoa commanding a high price. Unfortunately, this variety can be grown only under certain somewhat exacting conditions of soil and atmospheric environment.

(2) *Forastero,* which yields cocoa commanding generally a lower price, but the tree is much hardier and produces more regular crops than Criollo cacao.

(3) *Calabacillo,* a very hardy variety which can be grown under conditions unsuitable for either Criollo or Forastero. This type of cacao generally commands only a low price.

In addition to this botanical classification, cacao beans are usually graded by the manufacturer according to the geographic area in which they have been produced. Cacao from a particular area is known to possess a certain "quality" which is surprisingly constant. This special quality is the result of botanical variety or strain, climate, soil, cultivation and preparation; it cannot be attributed to any single factor. Fermented beans are usually graded by characteristics such as size of bean, colour of "break", aroma and taste. Of these, only size of bean can be measured, and manufacturers have not yet been able to define the biochemical factors which constitute or even contribute to high quality in cured beans. It has been suggested that quality of cacao may be influenced by the

relative abundance of tannins and other polyphenolic substances, low quality being associated with a high content of these ill-defined complexes, which are considered particularly to be responsible for a harsh bitter taste. It is also frequently stated that one of the beneficial effects of fermentation is oxidation of the tannins, which results in the partial removal of undesirable taste. Proof of these assumptions is still lacking, even although methods for the determination of tannins have recently been elaborated and applied to different types of cacao beans.

Two other biochemical components of the cacao bean which may readily be determined qualitatively, and which are of great economic importance, are fat and theobromine. Published analyses do not reveal any regular differences in the fat content of cacao beans of the different botanical types, but an investigation by Wadsworth (1) showed that there is a variation in the theobromine content of beans from different cacao-producing areas. These previous investigations of the biochemical composition of cacao beans have been carried out chiefly in temperate countries, and have concerned, almost exclusively, fermented beans. Before starting the present investigation, the decision had to be made as to whether fresh or fermented material was more likely to reveal differences in composition. The high quality Criollo types are usually fermented for only very short periods, while the coarser grades require comparatively long fermentation periods before they are suitable for the manufacture of chocolate. It may be surmised therefore, that the composition of fresh Criollo beans is nearly ideal for manufacturers. Since they require only a short fermentation, little change may occur in their composition as a result of this process. By similar reasoning, it may be argued that fresh beans of the coarser grades contain large quantities of undesirable substances affecting taste and flavour, and that the effect of long fermentation is to remove or alter these substances in such a way that the composition of the fermented beans more nearly approaches that of the Criollo type. Hence the largest differences in composition should be found in the fresh unfermented beans of the different varieties, and the detailed examination of such material should afford the best means of detecting differences in biochemical composition.

In the present preliminary investigation, the tannin, fat and theobromine contents of different types of fresh beans at varying stages of ripeness were determined, in an attempt to discover whether there is any constant relationship between these factors and "quality" in cacao. The measurement of possible variations in composition during ripening was deemed to be an essential consideration in this work. Progress was limited by a scarcity of material, since the investigation was begun towards the end of the 1935-36 crop, which finished in Trinidad very early compared with previous years. It was not always possible, therefore, to obtain samples which were truly representative of the different types of cacao.

Sampling.

One of the chief difficulties in an investigation of this kind is the collecting of bean samples typical of different quality groups. The cacao trees in Trinidad have been described by Cheesman as one of the most complex cacao populations in the world, and samples truly representative of contrasted high and low grade cacao are therefore difficult to obtain. Samples may be selected according to certain well-known superficial characteristics, which are often associated by the grower with quality. For instance, long narrow pods having thin, deeply furrowed husks, are believed to denote high quality cacao, while pods which are nearly spherical and having thick smooth husks are associated with low quality. Furthermore, samples may be selected, or at least classified, according to bean size, or internal colour of the beans. Large beans, having white or very pale purple internal colour, are thought to be indicative of high quality, while small beans, having a dark purple break, are associated with low quality. These superficial features do not provide completely satisfactory guides, however, since long narrow pods, possessing external Criollo characteristics, are often found to contain purple beans, whilst pale and dark-coloured beans may be found even in the same pod.

Another method of obtaining contrasted samples is to take material from different estates in districts with established reputations as to quality. The selection of samples for the preliminary investigation now to be described has been governed by these considerations. High and low quality types of Trinidad cacao have been compared with a Criollo type of cacao obtained fromVenezuela. Each sample comprised selected pods picked in the field and immediately brought intact to the laboratory. The physical characteristics of the pods and of the beans were then recorded before the chemical analyses were performed. Thus the size of the pod, percentage of husk, size, number and moisture content of the beans, percentage of kernel in the bean, and the moisture content of the kernel and testa were severally measured. In addition, the internal colour of the freshly cut beans was recorded, a sample being given a number according to an arbitrary colour scale.

Methods of Analysis.

After opening the pods, the beans were shelled, and the kernel and shell were weighed separately, and sampled for moisture determinations. The kernel was then passed through a mincing machine, but the shell had to be cut up with scissors, since it was too gummy for mincing. Fresh wet samples of kernel and shell were taken for tannin determination, and the remainder of

the material was oven-dried prior to estimating fat and theobromine. Tannins and theobromine were estimated by methods described in other sections of this report, and fat was determined by extraction for six hours with petroleum ether (b.p. 40-60°C) in a Soxhlet apparatus, after grinding as finely as possible in a mortar.

The analytical results are presented in Tables I, II and III. Table I shows the physical characteristics of the pods and beans in each sample; Table II gives the results of tannin determinations by three methods, whilst Table III gives the fat and theobromine contents of each sample.

Table I.

Physical Characteristics of Samples of Cacao Pods and Beans Used in Biochemical Investigations.

	Degree of Ripeness.	Av. Wt. of One Pod (g)	Husk in Pod (Per cent.).	No. of Beans Per Pod.	Av. Wet Wt. of One Bean (g)	Av. Dry Wt. of One Bean (g)	Kernel in Dry Bean (Per cent.)	Colour "Break" (Marks 0-6).
	TRINIDAD CALABACILLO TYPE.							
1	Unripe ¾ Full	426	73.6	42	2.58	0.47	51.1	1½
2	Unripe ¾ Full	618	76.7	42	3.19	0.64	61.9	2½
3	Unripe 9/10 Full	439	73.0	35	3.26	0.72	59.8	2½
4	Unripe Full	582	73.3	35	4.07	1.39	72.0	4½
Av.	Unripe	516	74.1	38	3.28	0.80	61.2	3
5	Ripe	482	78.1	37	2.76	1.36	80.2	5½
6	Over-Ripe	431	78.8	35	2.16	1.08	87.0	6
7	Ripe	638	83.3	42	2.39	1.08	77.8	4½
8	Over-Ripe	455	76.4	39	2.57	1.35	77.8	5½
Av.	Ripe	502	79.2	38	2.45	1.22	80.2	5½
	TRINIDAD FORASTERO TYPE.							
9	Unripe 9/10 Full	526	73.6	35	3.86	0.94	61.7	3½
10	Unripe 9/10 Full	417	68.1	40	3.09	1.21	61.2	3½
11	Unripe 9/10 Full	595	68.0	38	4.78	1.40	69.3	3½
Av.	Unripe	513	69.9	38	3.91	1.18	67.4	3½
12	Ripe	422	74.0	41	2.41	1.08	80.6	3
13	Over-Ripe	434	75.0	29	3.57	1.77	88.7	5
Av.	Ripe	428	75.0	35	2.99	1.42	84.1	4
	VENEZUELA CRIOLLO TYPE.							
14	Unripe Full	595	70.5	41	2.94	1.35	77.7	3
15	Unripe Full	545	73.5	38	3.50	1.29	80.5	2½
Av.	Unripe	575	72.0	39	3.22	1.32	79.1	3
16	Ripe	490	74.6	38	2.99	1.28	79.7	3
17	Ripe	533	74.0	31	3.58	1.76	86.4	3
Av.	Ripe	511	74.3	35	3.29	1.52	83.1	3

Table II.

Tannin Content of Different Types of fresh Unfermented Cacao Beans of Varying Stages of Maturity: Comparison of Tannin by Cinchonine Method and Goldbeaters' Skin Method with Tannin Derivatives by Acid Hydrolysis.

	Degree of Ripeness.	Tannin (Cinchonine Method) Per cent.		Tannin (Goldbeaters' Skin Index)		Phlobaphenes (Acid Hydrolysis) Per cent.	
		Kernel.	Shell.	Kernel.	Shell.	Kernel.	Shell.
	Trinidad Calabacillo Type.						
1	Unripe ¾ Full	5.1	8.1	8	8	3.0	1.7
2	Unripe ¾ Full	4.1	7.7	7	7	1.5	1.7
3	Unripe 9/10 Full	10.6	9.4	11	4	9.1	7.8
4	Unripe Full	11.8	3.1	20	2	11.0	6.3
Av.	Unripe	7.9	7.1	11	5	6.2	4.6
5	Ripe	6.9	7.9	7	4	3.0	4.5
6	Over-Ripe....	8.6	4.2	8	1	4.1	2.1
7	Ripe	4.5	1.9	7	7	0.5	1.0
8	Over-Ripe....	6.0	3.2	8	4	4.1	1.6
Av.	Ripe	6.5	4.3	8	4	2.9	2.3
	Trinidad Forastero Type.						
9	Unripe 9/10 Full	6.0	4.9	2	4	3.4	6.1
10	Unripe 9/10 Full	4.4	3.0	6	5	1.3	1.0
11	Unripe 9/10 Full	8.4	7.7	3	5	4.3	3.5
Av.	Unripe	6.3	3.9	4	5	2.3	2.6
12	Ripe	9.2	5.7	6	6	0.8	1.2
13	Over-Ripe....	9.0	6.7	18	4	6.6	6.8
Av.	Ripe	9.1	6.2	12	5	3.7	4.0
	Venezuela Criollo Type.						
14	Unripe Full	6.7	3.8	7	4	2.6	1.4
15	Unripe Full	5.5	1.7	9	7	2.1	1.4
Av.	Unripe	6.1	2.7	8	6	2.3	1.4
16	Ripe	4.3	3.1	9	7	1.2	1.7
17	Ripe	5.5	2.9	5	4	3.1	1.5
Av.	Ripe	4.9	3.0	7	6	2.1	1.6

Table III.

Theobromine and Fat Content of Different Types of Fresh Unfermented Cacao Beans of Varying Stages of Ripeness.

	Degree of Ripeness.	Theobromine Per cent.		Fat Per cent.	
		Kernel.	Shell.	Kernel.	Shell.
	Trinidad Calabacillo Type.				
1	Unripe ¾ Full	0.95	Nil.	36.7	1.97
2	Unripe ¾ Full	1.14	Nil.	40.3	2.50
Av.	Unripe	1.04	Nil.	38.5	2.23
7	Ripe	2.25	0.07	47.9	1.9
8	Over-Ripe	2.39	0.15	49.5	1.1
Av.	Ripe	2.32	0.11	48.7	1.5
	Trinidad Forastero Type.				
10	Unripe	2.01	0.01	48.1	1.7
12	Ripe	2.54	0.06	51.3	1.3
13	Over-Ripe	2.51	0.04	50.3	0.9
Av.	Ripe	2.53	0.05	50.8	1.1
	Venezuela Criollo Type.				
14	Unripe Full	1.94	0.35	43.4	4.1
15	Unripe Full	1.66	0.75	52.5	2.6
Av.	Unripe	1.80	0.55	47.9	3.3
16	Ripe	2.41	0.35	47.8	1.6
17	Ripe	2.25	Nil.	48.4	0.5
Av.	Ripe	2.33	0.17	48.1	1.0

Discussion of Results.

Physical Characteristics. (Table I.)

The size or weight of the pod seems to provide no indication of the degree of ripeness, but there is a regular increase in the percentage of husk in the pod as ripening proceeds. The *wet weight* of unripe beans from pods nearing maturity is much greater than the wet weight of beans from ripe pods, because of the much higher moisture content and higher percentage of shell and pulp in the unripe beans. As ripening proceeds, the moisture content of the beans decreases, while the dry weight of beans and the percentage of kernel in the bean increase rapidly, so that the *dry weight* of ripe beans is considerably greater than that of unripe beans. The best index of ripeness in pod or bean, according to these observations, is the *percentage of kernel in the oven-dry bean.* Unripe beans, even from full pods verging on ripeness, show at the most 72 per cent. kernel in the oven-dry beans, whilst ripe beans show from 78 to 88 per cent. of kernel in the dry beans. The figures for the unripe Venezuelan pods and beans must be regarded as exceptional. This sample was picked unripe and has been classified as such, but the pods were more than three weeks in transit, so that the beans must have been very nearly ripe when they were examined in the laboratory.

In considering the effect of type, the values for ripe pods only should be considered. The two types of Trinidad cacao were selected and classified chiefly according to external pod characteristics; they show considerable differences in the percentage of husk in the ripe pods, which is highest in the Calabacillo pods and lowest in the Venezuelan Criollo pods. The average relative size of the beans (wet and dry weights) accords with expectation, in that the smallest beans were found in the Calabacillo pods. The beans having the darkest purple internal colour were obtained from the Calabacillo pods, while the beans from the Trinidad Forastero and the Venezuelan Criollo pods showed paler tints of purple. The Venezuelan beans were quite highly pigmented, which shows that they were by no means the true Criollo type.

These records reveal the general basis on which the samples have been selected and classified, namely, by a number of physical characteristics usually associated with quality. There is a rather erratic variation between samples in the same group, mainly because of the limited number

of pods available at the time of sampling. More consistent results would doubtless have been obtained in samples taken at the height of the cacao crop, when a much wider range of representative material is available for selection.

TANNINS (Table II).

The results in Table II show no regular increase or decrease in the content of tannin substances as the beans ripen from three-quarter size to maturity. Unripe beans from Calabacillo pods show a higher content of tannin substances than ripe beans, but the reverse is the case for the Forastero pods, while for the Venezuelan Criollo, there is little difference between the tannin content of beans from ripe and unripe pods. The only really definite fact that emerges from these results is that tannin substances are present in large quantities in both the kernel and shell of cacao beans contained in immature or three-quarter sized pods, and probably in pods of even an earlier stage of growth.

The tannin content of different samples within the two types of Trinidad cacao is very variable, and no definite difference between the two types can be established by the recorded results. The beans from Venezuelan Criollo pods have a lower average tannin content than the beans from the Trinidad Forastero pods, but these results also are erratic, and further analyses should be made before this finding can be regarded as fully established. For the present set of samples, the Venezuelan Criollo beans show a lower tannin content by the cinchonine method, and a smaller amount of phlobaphane precipitate from acid hydrolysis. The results of the goldbeaters' skin test vary widely within the different groups, and no marked difference to this test can be distinguished between the two sets of samples.

THEOBROMINE (Table III).

The results in Table III show that the theobromine content of the cacao bean increases greatly during ripening to a maximum for the fully ripe stage. There seems to be little subsequent change in the theobromine content of the beans when the ripe pods are allowed to remain on the tree so as to become overripe, but the evidence on this point is still very scanty. The theobromine content of the shell and pulp of the fresh cacao bean is very low, being *zero* in some of the samples examined.

Little difference was found in the theobromine content of the three groups, though the Trinidad Forastero beans show a slightly higher average content of theobromine than the Venezuelan Criollo beans. Wadsworth obtained a theobromine content of 2.96 per cent. in the kernel of unfermented Trinidad cacao beans (Forastero type), and 1.52 per cent. for unfermented Ceylon beans (Criollo type). In general, Wadsworth's results indicate that the higher quality Criollo beans have a much lower theobromine content than the lower quality Forastero and Calabacillo. The present results show much smaller differences between the three groups than those indicated by Wadsworth's analyses, but a true comparison of the two sets of results is difficult, since the samples of unfermented beans examined by Wadsworth in England must necessarily have been a long time in transit, and some changes in composition may have occurred during the period which elapsed between the picking of the pods and the laboratory examination of the beans. Again, it should be noted that the present results were obtained from rather exceptional samples which should not be regarded as really typical of Trinidad cacao, since they were obtained out of the main crop season from pods which had matured and ripened under exceptional seasonal conditions.

FAT (Table III).

The results in Table III show that unripe beans from three-quarter sized pods contain a fairly large percentage of fat, but the fat content does not reach its maximum until the beans are fully ripe. Little difference in the fat content of fresh cacao beans is shown by the three groups, but the highest fat content seems to occur in ripe beans obtained from Forastero pods.

Thus the only definite relationship found in this investigation is an increase in theobromine during ripening. This observation cannot be considered to be conclusive, because it was not possible at the time to obtain an adequate number of truly representative samples. The results demonstrate that the problem cannot be solved by a small number of comparable analyses. A further examination of the tannin methods might be advisable; the methods employed take no account of the catechol tannins which Adam, Hardy, and Nierenstein (2) proved to occur in fresh cacao beans. Sampling requires careful consideration, and the degree of ripeness, seasonal variation, and even differences between pods on the same tree, may all tend to mask the biochemical distinctions between botanical types.

Summary.

(1) Preliminary investigations are described in which the biochemical composition of different botanical types of cacao beans is compared. Determinations have been made of the tannin, theobromine and fat contents of three types of fresh unfermented beans.

(2) These biochemical researches were initiated at the end of the 1935-36 crop season, when there was a great scarcity of cacao pods in Trinidad. Consequently, the preliminary investigations have been limited by the restricted amount of material available for examination.

(3) The analytical results show that there is a considerable variation in the tannin and theobromine content of fresh cacao beans from different types of pods. The differences are erratic, and laboratory examination has failed to

establish any definite correlation between tannin, theobromine and fat content for different botanical types of cacao.

(4) This erratic variation in the results may be caused by the limited range of material and the exceptional nature of the bean samples which were obtained from pods which had matured and ripened under somewhat abnormal climatic conditions.

(5) In order to prove whether or not tannins, fat, and theobromine are factors deciding "quality", further investigation of the tannin methods and of the method of sampling may be necessary.

References.

(1) Wadsworth, R. V.—"The Theobromine Content of Cacao Beans and Cocoa"; *Analyst*, 1922, 47, 152.

(2) Adam, W. B., Hardy, F., and Nierenstein, M.—"The Catechin of the Cacao Bean"; *J. Amer. Chem. Soc.*, 1931, 53, p. 727.

(2) THE EFFECT OF FERMENTATION ON THE BIOCHEMICAL COMPOSITION OF DIFFERENT TYPES OF CACAO BEANS.

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Fermentation is recognised in all cacao-growing countries as the best method of preparing raw cacao beans for the market. During fermentation, certain changes in taste and aroma take place which greatly enhance the commercial value of the bean. The exact chemical nature of these changes is not known, but amongst the most important effects is a presumed alteration of the tannin-like substances which is believed to result in a less bitter taste of fermented beans. Preliminary analytical data, recorded elsewhere in this report, demonstrate, however, that fermented beans may contain much larger amounts of tannin than unfermented beans. This result is contrary to the generally-accepted view that fermentation causes a reduction of the tannin content of cacao beans. In order to verify the conclusion, further tannin analyses of fermented and unfermented beans have been completed; the results are presented in this article.

Another important component of cacao beans affected by fermentation is theobromine, the alkaloid conferring stimulating properties on cocoa and chocolate. Wadsworth and Knapp have investigated the effects of fermentation on the theobromine content of the cacao bean (1), and their results show that, during fermentation, theobromine is removed from the kernel by solution and deposited in the shell. Hence fermentation causes a reduction in the theobromine content of the kernel and a corresponding increase in the theobromine content of the shell. Only a limited number of samples of unfermented beans was examined by Wadsworth, and the opportunity has therefore been taken to compare the theobromine content of a number of fresh unfermented beans with fermented beans of the same origin. In addition to tannin and theobromine determinations, the fat content of the different samples has also been measured. No attempt has been made, however, to study the intermediate stages of fermentation, and the composition of fresh cacao beans has merely been compared with that of fully fermented beans. The tannin, theobromine and fat contents of the different samples have been determined by the analytical methods described elsewhere in this series of articles.

Results.

The analytical results are presented in Table I, the composition of the kernel and of the shell being shown in separate sections. The tannin and theobromine contents are expressed as percentages of the oven-dry, fat-free bean, and the fat content as a percentage of the oven-dry bean.

Tannins.

The results indicate that, during fermentation, there is a definite *increase* in the tannin content of the kernel. The kernels of fermented beans show a larger amount of tannin substances by the cinchonine method, a higher goldbeaters' skin colour index, and a larger amount of phlobaphene precipitate than the kernels of fresh beans. These differences appear to be quite regular, and there are no exceptions in any of the paired samples examined. The present set of samples shows no regular or definite differences in the tannin content of the shell before and after fermentation.

Theobromine.

The results show close agreement with the findings of Knapp and Wadsworth (1), who proved that, during fermentation, there was a decrease in the theobromine content of the kernel, and a corresponding increase in the theobromine content of the shell. The amount of theobromine found in fresh kernels is less than that recorded by Wadsworth in unfermented Trinidad beans, but this difference may be explained by the exceptional out-of-crop samples used in the present investigation.

The results also indicate regular and definite differences in the theobromine content of the shell of different types of cacao beans. The theobromine content of the shell of fermented Calabacillo type of Trinidad beans is considerably

Table I.

Tannin, Theobromine and Fat Contents of Fresh Cacao Beans Compared with Fermented Beans of the Same Type.

KERNEL.

	Tannin Cinchonine Method Per cent.		Tannin Goldbeaters' Skin Test Index 1-20.		Phlobaphenes Per cent.		Theobromine Per cent.		Fat Per cent.	
	Fresh	Fermented.	Fresh	Fermented.	Fresh	Fermented.	Fresh	Fermented.	Fresh	Fermented.
Trinidad Calabacillo Type.										
A	6.9	13.8	7	10	3.0	6.2	2.25	2.01	47.9	55.1
B	8.6	12.2	8	10	4.1	6.3	2.39	1.75	49.5	54.2
C	6.0	10.6	8	12	4.1	7.4	2.40	1.80	47.8	54.4
Av.	7.2	12.2	8	11	3.7	6.6	2.35	1.85	48.4	54.5
Trinidad Forastero Type.										
A	6.1	13.9	6	9	3.1	4.4	2.45	2.37	53.2	56.8
B	6.0	13.2	7	10	2.9	4.4	2.46	2.39	48.1	56.6
C	7.6	12.7	6	10	5.7	6.2	2.30	2.13	49.6	54.3
Av.	6.6	13.3	6	10	3.9	5.0	2.40	2.29	50.3	55.9
Venezuela Criollo Type.										
A	4.3	13.2	9	11	1.2	5.2	2.41	2.21	47.8	53.8
B	5.5	13.8	5	10	3.1	4.2	2.25	2.18	48.4	52.4
Av.	4.9	13.5	7	10	2.2	4.7	2.33	2.20	48.1	53.1

SHELL.

Trinidad Calabacillo Type.										
A	7.9	7.8	4	7	4.5	4.4	0.07	2.37	1.9	3.3
B	4.2	3.4	1	5	2.1	4.3	0.15	2.36	1.1	3.5
C	3.2	4.1	4	6	1.6	3.2	0.09	2.21	0.9	2.1
Av.	5.1	5.1	3	6	2.7	3.9	0.10	2.31	1.3	3.0
Trinidad Forastero Type.										
A	5.7	5.2	6	5	6.8	3.7	0.08	2.25	1.3	2.6
B	6.7	4.7	4	5	3.6	2.1	0.16	1.91	0.9	2.9
C	4.9	4.6	5	6	1.2	1.1	0.12	2.02	2.1	1.8
Av.	5.8	4.8	5	5	3.9	2.3	0.09	2.06	1.4	2.4
Venezuela Criollo Type.										
A	3.1	1.7	7	7	1.7	1.6	0.35	0.82	1.6	3.8
B.	2.9	1.9	4	4	1.5	1.2	Nil.	0.78	0.5	2.9
Av.	3.0	1.8	5	5	1.6	1.4	0.17	0.80	1.0	3.2

higher than that of the shell of fermented Trinidad Forastero cacao, whilst the theobromine content of the shell of fermented Venezuelan Criollo beans is less than half that of the Trinidad beans. These results agree with Knapp and Wadsworth's theory of the effect of fermentation on theobromine distribution. The two groups of Trinidad beans were fermented for 10 days and 8 days respectively, whilst the Venezuelan beans are usually fermented for 60 hours. The amount of theobromine found in the shell of fermented cacao beans may therefore largely depend on the length of the fermentation period.

Fat.

The results indicate a slightly higher fat content in the fermented beans than in the unfermented beans. The fat content of the beans may not change appreciably during fermentation, but there is a loss of sugars and other soluble substances in the sweatings, so that the percentage of fat shows an apparent increase in the fermented beans.

Discussion.

Of the three biochemical components of the cacao bean so far examined, theobromine appears to show the most regular variation, both between

fermented and unfermented cacao, and between cacao beans of different types. In view of the large quantities of theobromine found by Wadsworth (2) in the kernels of beans of low quality cacao (more than three per cent. on dry, fat-free material), it seems possible that theobromine rather than tannin may be chiefly responsible for the harsh and bitter taste of low quality cacao, and one of the beneficial effects of fermentation may be the reduction of the theobromine content of the kernel of the bean. The present results indicate that the theobromine content of the *shell* of fermented cacao beans may be a useful index of the duration of the fermentation period, a high theobromine content indicating long fermentation, and *vice versa*. In discussing Wadworth's results, Knapp (2) has already suggested that the theobromine content of cacao beans may be a useful guide to botanists in the difficult task of classifying cacao grown in different countries, and future investigations should therefore include an examination of the theobromine content of fresh beans of different types, and of the effect of fermentation on the theobromine content of the kernel and shell.

With regard to tannins, the preliminary results indicate that the process of fermentation causes an *increase* in the tannin content of cacao beans. This is contrary to generally accepted ideas, but it may be explained on the grounds that fresh cacao beans contain a considerable quantity of catechin which, during fermentation, is oxidised to produce tannins which stain goldbeaters' skin, and which form a precipitate with cinchonine sulphate. Adam, Hardy and Nierenstein (3) have demonstrated the presence of catechin in fresh cacao beans, and Adam (4) has devised a method for its quantitative estimation. He has shown that no catechin can be detected in fully fermented beans.

At a joint meeting of the Society of Public Analysts which the Food Group of the Society of Chemical Industry held on 5th February, 1936, the tannin and alkaloid contents of tea and coffee were specially considered (5). In the course of the discussion that followed, Dr. H. H. Mann (5) pointed out that, as a general rule, high priced teas have a higher tannin content than low-priced teas, though there are many exceptions. It would appear, therefore, that previous ideas concerning the effects of tannin substances on taste and flavour of tea, coffee and cocoa may have to be revised. A high total tannin content may be positively associated with desirable taste and flavour. The harsh bitter taste of low quality cacao beans, hitherto associated with tannins, may be partly caused only by one fraction of the tannin complex normally present in the bean, and it must be assumed that many of the present methods of analysis fail to separate these particular "undesirable" tannins from other polyphenolic substances which may be unimportant in controlling quality, or which may be positively associated with desirable qualities of taste and flavour. For complete elucidation of this problem, more selective methods of analysis will have to be elaborated. The rôle of tannins in partly controlling the quality of cacao beans or cacao products is evidently not a simple case of relative scarcity or abundance. The nature, or perhaps the degree of oxidation, of a few specific compounds may have great importance. On the other hand, it may eventually be proved that tannin substances are entirely unconnected with quality in cacao, or at least are relatively unimportant. At the meeting mentioned above, Mr. H. S. Redgrove stated that taste and flavour should be considered as different phenomena. Tannin might affect the taste of tea and coffee, but flavour could not possibly be caused by a non-volatile substance such as tannin, but is more likely caused by an essential oil. The presence of an essential oil in fermented cacao beans has already been proved by Bainbridge and Davies (6), though the relative quantities present in different grades of cacao have not yet been determined.

Summary.

(1) A prelimnary investigation has been made of the effect of fermentation on the biochemical composition of cacao beans.

(2) Fresh unfermented beans have been compared with fully fermented beans of the same type with regard to their tannin, theobromine and fat contents.

(3) Fermentation appears to cause an increase in the total tannin content of the kernel of the cacao bean. This increase of tannin during fermentation is indicated by three different methods of analysis.

(4) The significance of the present results in relation to future investigations and the rôle of tannins in relation to quality of cacao beans are discussed.

(5) During fermentation, there is a decrease in the theobromine content of the kernel of the bean, and a corresponding increase in the theobromine content of the shell. These results agree closely with the previous findings of Wadsworth and Knapp.

(6) The theobromine content of the kernel of *fresh* cacao beans may furnish a useful index of botanical type, while the theobromine content of the shell of *fermented* beans may provide a useful index of the duration of the fermentation process.

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(3) A NOTE ON THE ESTIMATION OF THEOBROMINE IN CACAO BEANS.

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A Critical examination of the methods available for the estimation of theobromine in cacao beans has been made by Wadsworth (1), who devised a new method, using tetrachlorethane as solvent. Later he applied this method in the examination of different types of cacao beans (2). Wadsworth's method is now recognised as the simplest and most accurate method so far devised for the estimation of theobromine in cacao beans and cacao products.

In applying this method to fresh and fermented cacao kernel and shell, certain modifications have been adopted which reduce the number of necessary operations, thus rendering it more suitable for the examination of a large number of samples. Wadsworth extracted the theobromine with tetrachlorethane by boiling for half an hour in a conical flask; the mixture was then filtered, the filter paper returned to the conical flask, and the mixture again boiled for half an hour with a fresh batch of solvent. This process was repeated three or four times. In our modified method, the material is extracted for three hours in a Soxhlet extractor, which siphons over once in every 10 to 15 minutes, so that the material is extracted with 12 to 15 batches of fresh hot (not boiling) solvent. When this modification was first introduced, it was found that, owing to the high boiling point of the solvent, the vapour condensed in the side tube, and did not reach the extraction chamber. This difficulty was overcome by wrapping several layers of insulating tape round the side-tube of the Soxhlet vessel, thus preventing excessive cooling and condensation.

A second modification concerned the final distillation. It was found convenient to reduce the volume to about 15 cc. in the distilling flask (*i.e.*, before the precipitation of theobromine begins). This small volume of solvent was then transferred to a 100 cc. beaker, and the flask washed out with a small quantity of the solvent. Evaporation of the solvent was then continued in the beaker until the point when precipitation of theobromine began. By carrying out the actual precipitation of theobromine in the small beaker instead of in the distilling flask, the transference of the precipitate to the filter paper is greatly facilitated. After addition of 70 cc. ether, the mouth of the beaker was closed by a large cork and the mixture left overnight. During filtration, the liquid was cooled in ice, since the boiling point of ether is only 6°C. above the average day temperature in Trinidad.

Method.—8 to 10 g. of finely-ground oven-dried fat-free material are placed in a porcelain dish, and mixed with 2 to 3 g. freshly calcined magnesia. The mixture is then triturated with 12 to 18 cc. of water and placed on a water-bath for 30 minutes to dry it partially, the mass being mixed at intervals to prevent any part becoming completely dry. It is then transferred to a filter paper, placed in an extraction thimble, and extracted for three hours with tetrachlorethane in a Soxhlet apparatus. An air condenser is used instead of the usual water condenser. After the extraction, the solvent is distilled off until the volume is reduced to about 15 cc.; the residue is transferred to a 100 cc. beaker and evaporation continued until theobromine begins to crystallise. 70 cc. methylated ether are added, the mixture allowed to stand overnight, filtered through a tared filter paper, washed with ether, dried at 100°C., and weighed. To this weight is added 0.004 g., representing the amount of theobromine dissolved by the ether used in precipitating and washing.

In order to test whether these modifications had affected the accuracy of the results, three samples of fermented cacao kernel were used for the estimation of theobromine by Wadsworth's method as published, and by the modified Soxhlet method. The results obtained are set out in Table I.

Table I.

Theobromine Content of Fermented Cacao Beans: Comparison of Different Methods of Extraction.

Kernel Sample.	Percent. Theobromine on Oven-dry Fat-free Material.					
	Normal Extraction.			Soxhlet Extraction.		
	A.	B.	Mean.	A.	B.	Mean.
I ..	1.80	1.84	1.82	2.21	2.30	2.25
II ..	1.58	1.50	1.54	2.12	2.21	2.17
III ..	1.27	1.31	1.29	1.75	1.80	1.77

The results show that better extraction of theobromine is obtained with the Soxhlet method, as much as 40 per cent. increase in the apparent theobromine content being obtained by continuous extraction. It is worthy of note that Wadsworth (2) obtained a higher figure (2.69 per cent.) for Trinidad fermented beans than those given in Table I obtained by his method without modification, and the results obtained with the Soxhlet extractor correspond more closely with his figure. These discrepancies may be explained by the fact that Wadsworth ground the nibs in a warm mechanical mortar, reducing the particle size to 0.005 inch (corresponding to a 120-mesh sieve), whereas no such apparatus was available

for the present work. Cacao kernel cannot be ground to a high degree of fineness in the ordinary laboratory mortar, and, although care was taken to grind the material as finely as possible, the particles were still relatively large. Extraction in the Soxhlet may have compensated for the coarser grinding by continuous percolation of the material with fresh solvent.

References.

(1) Wadsworth, R. V.—"The Estimation of Theobromine in Cacao and its Products"; *Analyst*, 1921, 46, pp. 32-37.

(2) Wadsworth, R. V.—"The Theobromine Content of Cacao-Beans and Cocoa"; *Analyst*, 1922, 47, pp. 152-161.

(4) THE TANNINS IN CACAO BEANS.

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The astringent taste of the lower grades of cacao is generally attributed to the presence of an excess of substances resembling tannins, and the changes in colour and flavour which take place during cacao fermentation are believed to be caused by alteration of these tannin-like substances. A comprehensive review of the literature concerning cacao tannins has recently been published by Knapp (1), and his survey shows that very little is known of the composition of the "tannins" present in cacao. As early as 1909, the presence in cacao beans of a catechin-like substance (considered by some to be the precursor of cacao tannins) was demonstrated by Ultee and Van Dorssen, and later, Adam, Hardy and Nierenstein (2) proved this substance to be a true catechin. Cacao catechin was identified by Nierenstein as l-acacatechin, but this conclusion has been disputed by Freudenberg (3). Adam (4) devised a method for the quantitative estimation of catechin in cacao beans, and showed that, during fermentation, the catechin disappears, being entirely absent in fully fermented beans. Cacao catechin is evidently not a true tannin, since it does not give positive results with many of the well-known tannin tests, *e.g.*, it does not stain goldbeaters' skin, nor does it form a precipitate with gelatin and alkaloids, but it readily undergoes oxidation into tannin-like substances which give these tannin tests. It seems probable, therefore, on the basis of Adam's work, that, during fermentation, the catechin is changed into true tannins, but the exact nature of the change is unknown. Although several hypotheses have been proposed, none of them is supported by adequate evidence, and the general conclusion must be drawn that no satisfactory explanation is yet forthcoming of the difference in astringency of the commercial grades of cacao.

Methods of Analysis.

Tannins.

A survey of the methods of estimating tannins has recently been published by Ainsworth Mitchell (5). The most suitable method for the determination of tannins in tea, coffee and cacao appears to be a modification of Chapman's gravimetric method, in which the tannin is precipitated by cinchonine sulphate. Norman and Hughes (6) determined the tannin content of tea by three different methods, namely (*a*) the cinchonine method, (*b*) the Löwenthal method, and (*c*) the hide powder method. They concluded that, in order to obtain comparable results, the method used must be exactly specified and rigidly standardised. Adam (4) and Jensen (7) have both adapted the cinchonine method to the determination of tannin in cacao beans, but their methods differ somewhat in detail, and the results obtained by Jensen are numerically much higher than those obtained by Adam. The chief differences between the two methods concern the temperature of extraction and the reaction of the extracting medium. Adam carried out his extraction at 65°C., and made no attempt to neutralize the natural acidity of the beans. Jensen, on the other hand, extracted at a higher temperature (95-98°C), and neutralized the acidity by adding a definite amount of 0.1N caustic soda solution. The differences in results obtained by these two workers suggest that the temperature and reaction of the extracting medium are very important, and must be standardised in order to obtain consistent values.

At this preliminary stage of our investigations, it was considered advisable to standardise Jensen's method (particularly with regard to temperature and reaction during extraction), and to apply it to fresh and fermented cacao beans of different types.

The tannin substances present in fresh cacao beans are not stable, and they begin to alter as soon as the beans are removed from the pod. It is therefore essential that little time should elapse between opening the pods and extracting the beans or shells with hot water. In practice, the pods were opened in the laboratory, the beans removed from the pod and separated into (*a*) kernel and (*b*) pulp and shell. The kernel was passed through a mincing machine, but the mucilaginous pulp and shell had to be cut by hand into small pieces. Suitable amounts of the fresh wet material were taken for extraction. Moisture, fat and theobromine were determined on separate portions.

The analytical method finally applied differs from Jensen's method in several respects, notably,

(*a*) addition of ammonium acetate to the extracting solution to act as a buffer against changes in reaction and to aid filtration,

(*b*) preliminary titration to determine the amount of alkali necessary for neutralising the free acids contained in each sample. Jensen used a fixed amount of 0.1N caustic soda, but it was found that different types of cacao require different amounts of alkali,

(*c*) standardisation of the weights of material from each sample, so that, in each case, approximately the same weight of oven-dry, fat-free material was taken for extraction,

(*d*) use of kieselguhr as an aid to filtration after extraction. This was necessary in order to obtain a clear filtrate, particularly with some shell samples from fermented beans, which gave a viscous gummy extract.

Methods.—The following weights of raw material, based on average values for moisture and fat content, have been standardised for tannin determinations:—

(*a*) Fresh, wet, ripe or unripe pulp and shell	50 g.
(*b*) Fresh, wet, over-ripe, pulp and shell	30-40 g.
(*c*) Cured dry shell	10 g.
(*d*) Fresh, wet, immature kernel	40 g.
(*e*) Fresh, wet, unripe (but full) kernel	30 g.
(*f*) Fresh, wet, ripe or over-ripe kernel	25 g.
(*g*) Cured, dry, kernel	17 g.

For the preliminary titration, two to ten g. of the material (*i.e.* one-fifth of the amount required for extraction) are boiled for one minute with 100 cc. water. The mixture is cooled and titrated with 0.1N caustic soda, 0.2 per cent. phenolphthalein solution being used as an external indicator. The titration figure multiplied by five gives the amount of the standard soda required to neutralise the free acids during extraction.

In the extraction, weighed amounts of material as above, together with five g. of ammonium acetate, are placed in a 1000 cc. beaker with 460 cc. water, and the requisite amount of 0.1N soda required to neutralise the free acids as determined by experiment. The mixture is heated to 95°C. on an open flame, and then kept at 95-98°C. for 30 minutes in a boiling water bath. Five g. filter-aid are then added and the mixture stirred and cooled to room temperature, poured into a 500 cc. graduated flask, and made up to the mark. Filtration is carried out through a Buchner funnel (18.5 cm.), the first 20-30 cc. of the filtrate being discarded.

Tannin.—Precipitation by cinchonine sulphate is carried out on 50 cc. extract as in Jensen's method, and the precipitate is collected on counterpoised filter papers and dried in the manner suggested by Jensen.

Phlobaphenes.—*i.e.*, insoluble red derivatives of tannins, produced by prolonged boiling with hydrochloric acid. Duplicate aliquots of 50 cc. of the clear water extract of shell or kernel are placed in 500 cc. beakers, and 200 cc. water *plus* 25 cc. concentrated hydrochloric acid are added. The mixture is boiled for four hours on a sand-bath, the liquid lost by evaporation being replaced with ten per cent. hydrochloric acid. The red phlobaphene precipitate is collected on counterpoised filter papers, washed with cold water, dried in a water-oven and weighed.

Goldbeaters' Skin test for tannins.—In addition to the above quantitative estimations of tannins and phlobaphenes, a qualitative test was carried out on each sample by the goldbeaters' skin method. This is the only specific test which involves the tanning properties of a tannin substance. The method was originally elaborated by Atkinson and Hazleton (8), and its application was later extended by Price (9), who gives full details of the procedure. In this case, the stained skins were mounted on cardboard, and gave a roughly quantitative measure of the amount of tannin in the sample. Each skin was classified by an arbitrary index of one to 20; number one corresponding to the faintest detectable stain, and number 20 to the dark stain produced by a 0.1 per cent. solution of tannic acid.

Analytical Data.

These three methods were applied to a number of cacao bean samples, both fresh and fermented in order to test whether reproducible results could be obtained. The results are presented in Tables I and II.

The figures show that consistent results can be obtained by all three methods. With the cinchonine method, the agreement between duplicate analyses is particularly good for fresh unfermented material, but fermented beans show considerable variations between replicates. The gummy substances present in the extract of fermented beans caused difficulties in filtration and precipitation, and this was particularly marked in samples which had been stored for some months. For comparative purposes, however, the results are consistent enough to warrant further application of the cinchonine method to the comparison of the tannin content of different types of cacao beans, both fresh and

fermented. The goldbeaters' skin method, though only roughly qualitative, gave comparative results which agree fairly well with those of the cinchonine method, and serve as a useful check. The phlobaphene method also gave quite consistent results, and lack of exact knowledge of the chemistry of cacao tannins renders it a useful adjunct to the other methods.

Discussion of Results.

The most striking feature of the data in Tables I and II is the higher percentage of tannin in fermented as compared with unfermented cacao beans. This is rather surprising, since it is frequently stated in the literature that fermentation causes a decrease in the tannin content. The number of analyses tabulated is

Table I.

Determination of Tannin in Cacao Beans: Test of different Methods applied to Samples of Fresh and Fermented Cacao Bean Kernel.

		Wt. of Fresh Mat. (g).	Wt. of Oven-dry Fat-free Mat. (g).	N/10 NaOH Added (cc.)	Reaction of Extracts (pH)	Wt. of Chincho-nine Tannate Ppt. (g).	Tannin in Oven-dry Fat-free Mat. Per cent.	Tannin Mean Per cent.	Phloba-phene in Oven-dry Fat-free Mat. Per cent.	Gold-beaters' Skin Index (No. 1 to 20).
	I.—Kernel of Fresh Beans from Pods of Calabacillo Type.									
A.	1	25	7.23	17.5	6.2	0.0800	6.08	6.03	2.76	8
	2					0.0786	5.98			
	3					0.0786	5.98		2.76	
B.	1	25	7.23	17.5	6.0	0.0750	5.70	5.71	2.76	9
	2					0.0748	5.69			
	3					0.0752	5.72		2.79	
	II.—Kernel of Fresh Beans from Pods of Forastero Type.									
A.	1	25	7.61	15.0	6.3	0.0836	6.04	6.05	3.12	9
	2					0.0836	6.04		—	
	3					0.0841	6.08		3.21	
B.	1	25	7.61	15.0	6.2	0.0836	6.04	6.07	3.21	9
	2					0.0842	6.08			
	3					0.0842	6.08		3.15	
	III.—Kernel of Fresh Beans from Pods of Calabacillo Type.									
A.	1	25	7.62	20.0	6.3	0.0535	3.86	3.84	1.31	7
	2					0.0534	3.85			
	3					0.0527	3.80		1.31	
B.	1	25	7.62	20.0	6.2	0.0528	3.81	3.82	1.31	7
	2					0.0532	3.84			
	3					0.0528	3.81		1.31	
	IV.—Kernel of Beans from High-Grade Trinidad Fermented Cacao.									
A.	1	17	6.58	30.0	6.2	0.1600	13.37	13.95	4.41	11
	2					0.1694	14.15			
	3					0.1712	14.30		4.41	
B.	1	17	6.58	30.0	6.2	0.1500	12.53	13.23	4.44	11
	2					0.1730	14.46			
	3					0.1520	12.70		4.35	
	V.—Kernel of Beans from Low-Grade Trinidad Fermented Cacao.									
A.	1	17	7.36	30.0	6.5	0.1712	12.80	13.00	6.32	11
	2					0.1772	13.25			
	3					0.1732	12.95		6.38	
B.	1	17	7.36	30.0	6.6	0.1714	12.81	12.62	6.38	11
	2					0.1670	12.47			
	3					0.1682	12.57		6.35	

Table II.

Determination of Tannin in Cacao Beans: Test of Different Methods applied to Fresh and Fermented Cacao Bean Shell.

		Wt. of Fresh Mat. (g)	Wt. of Oven-dry Fat-free Mat. (g.)	N/10 NaOH Added (cc.)	Reaction of Extracts (pH.)	Wt. of Cinchonine Tannate Ppt. (g.)	Tannin in Oven-dry Fat-free Material Per cent.	Tannin Mean Per cent.	Phlobaphene in Oven-dry Fat-free Mat. Per cent.	Goldbeaters' Skin Index (No. 1 to 20).
	I.—Shell of Fresh Beans from Calabacillo Type Pods.									
A.	1	32	6.0	52.5	6.1	0.0444	4.06	4.04	1.67	4
	2					0.0442	4.05			
	3					0.0436	4.00		1.67	
B.	1	32	6.0	52.5	6.1	0.0436	4.00	3.97	1.56	4
	2					0.0432	3.96			
	3					0.0436	4.00		1.67	
	II.—Shell of Beans from Low-Grade Trinidad Fermented Cacao.									
A	1	10	6.4	20.0	6.4	0.0792	6.81	6.41	3.26	5
	2					0.0700	6.01			
	3					0.0746	6.41		3.47	
B.	1	10	6.4	20.0	6.4	0.0684	5.88	6.02	3.17	6
	2					0.0697	5.99			
	3					0.0729	6.26		3.25	

not sufficient for generalisation, and the question was investigated further. The additional information is discussed in another section of this report.

With regard to the reliability of the methods employed, it is evident that the methods have been standardized sufficiently accurately to give comparable results, but it must be emphasised that the tannin substances which are being measured may vary widely, depending on the particular analytical procedure employed. For instance, the goldbeaters' skin method may detect only one or two substances in a group which may form precipitates with cinchonine sulphate. Further, there may be present a number of tannin-like substances which are precipitated by cinchonine sulphate, and yet do not form red insoluble phlobaphene compounds when boiled with dilute acid.

It is almost certain that the " tannin " present in cacao beans is not a single substance but a mixture of tannins and tannin derivatives representative of many stages of oxidation. It is therefore probable that the tannins present in fermented beans are different from the tannins in fresh beans. If the flavour and taste of cacao are controlled by the presence of tannin-like substances (which has not yet been proved), it does not necessarily follow that all the tannins or tannin derivatives are involved.

It is a biochemical problem of considerable economic importance to discover which particular polyphenolic substances are responsible for the astringent taste of low-grade cacao. A partial solution of the problem may perhaps be obtained by means of a different procedure. Various methods of tannin analysis might be applied to carefully-selected type samples of different grades of cacao, and some method may then be discovered which differentiates between " high " and " low " quality cacao beans. It may then be assumed that this particular method estimates that part of the tannin complex which is responsible for the difference in taste and flavour. Preliminary investigations to test this possiblity have been carried out, employing the three analytical methods outlined above ; the results are presented and discussed in later sections of this report.

Summary.

1. Various published methods for measuring the tannin content of cacao beans have been examined with a view to selecting one suitable for the routine determination of the tannin content of a large number of samples of cacao beans and cacao products.

2. The details of three methods were standardised, and these methods were applied to the examination of a number of samples of cacao beans.

3. The results indicate that a modification of the cinchonine sulphate method is suitable for the determination of tannin in fresh beans. With fermented beans the procedure is more troublesome, but even for this type of material the method may also be used for comparative purposes.

4. The amount of phlobaphene produced by acid hydrolysis may provide useful additional data for comparing the tannin content of different samples. The method is simple and rapid, and the results show fair agreement with the amounts of tannin indicated by the cinchonine method.

5. The goldbeaters' skin qualitative test for tannins has also been applied to a series of cacao samples. The stained skins were graded on a roughly qualitative scale for comparison with the results of the two gravimetric methods.

6. The possible utility of the three methods as a means of differentiating between the various grades of cacao is discussed.

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(5) BIOCHEMICAL PROBLEMS IN CACAO PRODUCTION.

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Introduction.

While the final judge of quality in chocolate is the public, it is to the manufacturer that we must turn for an interpretation of that judgment in terms of quality of cacao. If the type of cacao required by each manufacturer could be stated and described chemically, the work of the geneticist and the planter would be more clearly defined, and provision might perhaps be made for satisfying every requirement. On the other hand, if the quality characteristics of the existing genetic types of cacao were known, and their relationship to chocolate manufacture were established, the manufacturer would be in a better position to choose his raw material from the supplies available.

Three main genetic types of cacao are nowadays recognized, namely, Criollo, Forastero and Calabacillo. The white Criollo bean has a smooth, sweetish taste, while the dark purple Calabacillo bean has a harsh, bitter taste, and the several grades of purple Forastero lie between these two extremes. Colour of bean is thus a striking feature, since increasing depth of purple is apparently coincident with increasing bitterness of taste. Fermentation affects these types differently, for the Criollo bean requires only 60 hours, Forastero as much as ten days, while it is doubtful if the Calabacillo bean can be satisfactorily fermented even in 20 days. Enzyme action during drying may also be responsible for the development of flavour. Roasting prior to manufacture is known to bring out the full flavour and aroma of chocolate, and the drastic chemical reactions which take place during roasting must be related to the composition of the bean. Tannins, fats, theobromine, lecithin, starches, sugars and proteins may be involved in the definition of "quality". Apart from these biochemical components, numerous factors connected with the environment of the tree, such as soil, rainfall and atmospheric humidity, may also be involved. Any or all of these factors may be responsible for the differences in flavour.

As a connecting link between the growing cacao tree and the chocolate factory, the biochemist is thus presented with a great many interrelated problems, which have as their common bond the ultimate definition of quality in cacao. If these problems were solved, the geneticist would be in a position to breed trees with the particular properties required by the manufacturer, and the existing grades of cured cacao could be clearly demarcated according to the type of chocolate for which they are suitable.

The Problems.

Type.—From the botanical point of view, we know that certain areas produce cacao which commands a relatively high price, either because of its genetical type, or because of its environment, or both. The higher price paid for "fine quality" cacao may be explained by the fact that the demand is greater than the supply, but it is generally agreed that high quality cacao yields a smooth-tasting chocolate which is particularly desirable for certain purposes.

We know also that certain trees in any one district, irrespective of type, give a higher yield than the surrounding trees which presumably are growing in the same environment. For the past five years, the chief object of the botanical

programme of the Cacao Research Scheme has been the improvement of yield and "quality" by propagation from selected trees. The criteria of selection have been yield of wet cacao per tree (allowance being made for tree size), and weight of the individual beans. Any other consideration of quality may have to be postponed until bulk samples can be obtained by the vegetative propagation of selected trees. The issue is thus straightforward as regards improvement of yield, but lack of knowledge of the attributes of "quality" renders other problems much more difficult to solve. The highest price is paid for fermented cacao of the white bean Criollo type. The Criollo tree appears to require special conditions of soil and climate, and its cultivation is so limited that the balance of supply and demand contributes to its high value. Nevertheless, the fact remains that the white Criollo bean has quality attributes which are not possessed by the purple Forastero and Calabacillo types.

The question hence arises, what is the essential difference between Criollo and Forastero cacao? Is it absence of purple pigment, or is it a difference in amount of tannin or theobromine, or is it a combination of these factors with others which are at present unknown? If the absence of purple colour in the true Criollo bean is the main criterion of its particular quality, then a white Forastero bean might combine high-yielding and high-quality characteristics with increased hardiness of growth. White Forastero beans indeed have been discovered, and the argument may be pushed even further, since white beans have also been found in Calabacillo pods, so that the extremely hardy Calabacillo tree might also yield good quality cacao.

On the other hand, if the presence or absence of colour is merely an indication of other characteristics, it may be possible to define and estimate these "quality" factors, and to assess their influence on chocolate manufacture. The geneticist might then be able to incorporate the desirable characters into a high-yielding and hardy tree, even to the extent of producing separate types for different manufacturing purposes. The relationship between quality and soil conditions may introduce further problems, but at present the biochemical reactions of the cacao tree to its environment cannot even be conjectured.

Fermentation.—Fermented beans realise a higher price than unfermented beans of the same type; hence fermentation causes desirable changes in the composition of the bean. Yet fermentation cannot overcome differences in type; for example, poorly-fermented Ecuador cacao is generally priced slightly higher than well-fermented Trinidad or Grenada cacao. Thus fermentation alters the Forastero bean in such a way that its undesirable characteristics are modified, and the chemical changes involved may partly determine what constitutes quality. The striking change in colour from purple to brown during curing shows that the purple pigment is involved in some way. Furthermore, Wadsworth has shown that, during fermentation, there is a reduction of the theobromine in the kernel, and changes in the tannin complexes have also been observed, while the percentage of fat remains practically constant during fermentation. It is possible that such changes in the components may play their parts in the general improvement produced by fermentation.

From the planter's point of view, the changes during fermentation are at present more important than the composition of the fresh bean, since the introduction of high-bearing trees of good quality can be carried out only gradually, and the planter must make the best use of the cacao which occurs on his estate. Many studies have been made of the fermentation process, some from the microbiological aspect, and a few from the chemical side. The microbiologists have described in some detail the succession of changes which result in destruction and removal of the pulp, but the biochemical reactions involved are not fully known. A number of analyses have been performed on fully fermented, partly fermented, and unfermented beans, and careful records have been taken of the conditions of temperature, moisture and acidity during fermentation. It has not been possible, however, to correlate these observations with "quality" in the cured bean, except that fermented beans are believed to have better "quality" than unfermented beans.

Some authorities have suggested that fermentation, as such, is unnecessary, and that a better product may be obtained by other means. None of these alternative methods has received strong support from the planter, mainly because such methods are laborious and expensive. Thus the established process of fermentation followed by sun-drying, still remains the most convenient method of curing cacao beans in large quantities. It is peculiar to cacao that the commercial product varies between two extremes—fermented and unfermented—and yet the difference in price paid by the manufacturer hardly justifies the skill and care required in the preparation of well-fermented beans. It is generally true that the further the botanical type is removed from the Criollo variety, the greater is the skill required in curing. The difference in time of fermentation between pale-coloured Criollo beans and purple Forastero and Calabacillo beans is one of the most striking features connected with genetic type. While Criollo is sufficiently fermented after 60 hours, Forastero and Calabacillo beans require much longer periods, up to ten or 11 days. This time is necessary in order to change the colour of the bean from purple to brown, and thus fermentation is related in some way to the presence of purple pigment. If the longer

fermentation period is required solely to alter the colour of the bean, it may cause more drastic changes in the other components, and consequently give a final product of different flavour and aroma. Further, if taste is directly related to the amount of pigment, white or non-pigmented Forastero beans should require only 60 hours' fermentation. On the other hand, if taste is not connected directly with colour, the different flavour and aroma of cured purple beans may be accounted for by the more drastic alteration of other components, and thus any desired degree of "fullness" of flavour could be obtained by fermenting white Forastero beans for the appropriate period. An investigation of the function and significance of the purple pigment of cacao would thus appear to be closely involved in the general study of the fermentation process as well as of the effects of genetic selection.

The tannin compounds present in the cacao bean have received considerable attention in the literature on fermentation, but it is noteworthy that no striking differences in tannin content have been found between pale and dark-coloured beans. This may be partly accounted for by difficulties in estimating tannins, whose rapid oxidation renders it uncertain whether or not changes have taken place during the preparation of the sample. If the purple-coloured kernels are removed from fresh Forastero beans and then passed through a mincing machine, the mass turns brown within a few minutes, and the purple colour is completely masked or disappears almost entirely. This colour change may be prevented by boiling the beans before removing the testas; it is evidently controlled by enzyme action. The white kernels of Criollo beans show a rapid development of brown colour similar to that found on the cut surface of an apple, a change which is known to be caused by the oxidation of tannins. It is possible that the bright brown colour of fermented Forastero may really be a mixture of brown and red colours, the brown colour being developed by oxidising tannins, and the red colour developed by the effect of acetic acid on the purple anthocyan-like pigment.

Drying.—After fermentation is judged to be complete, the beans are dried, either in the sun or by means of artificial driers. During drying, enzyme action proceeds at a rate depending partly on the rapidity of water loss, but a great disadvantage of artificial drying is its excessive rapidity, which may cause undesirable biochemical changes. The chief desirable change produced by slow sun-drying mainly concerns the oxidation of cacao tannins with a concomitant reduction in astringency. It is likely that fermentation was originally an accidental accompaniment of drying; the early Central American planter dried his cacao as rapidly as the weather would allow, which meant that the beans were heaped up under cover overnight and during rainy periods, and thus they were allowed to ferment slightly *at different moisture contents.* In the present-day process, fermentation is usually complete before drying begins, sufficient time not always being allowed for the oxidative enzymes to develop their full desirable effects.

Roasting.—By far the most drastic treatment applied to cacao beans is roasting prior to the manufacture of chocolate. During this process, flavour and aroma are fully developed. A certain amount of research has been carried out on the effects of roasting, but the significant changes have not yet been conclusively elucidated, chiefly because the analytical methods which hitherto have been applied to cacao products are not selective enough to demonstrate the complex intermediate changes. The quality of the roasted beans is certainly the final criterion, but this must be related in some way to the chemical composition of the fresh bean and its internal changes during curing.

Chemical Components.—If the general quality level of raw cacao produced in all countries were to be raised, the price paid by the manufacturer would not rise proportionately, because the market value of his products would still be the same. On the other hand, could it be proved that a certain component of the raw bean, for example cacao fat, operates as a controlling factor in the cost of manufacture, then the market value of cacao might be seriously affected. Thus the fat content of the cocoa nib probably already affects the cost of manufacture of chocolate, because, with low fat content, a relatively larger amount of cocoa butter must be added in the process. If it were found possible, therefore, to increase the natural fat content of cacao beans by genetic selection, the value of the new raw material would be greater than that produced at the present time. It is by no means certain that this object could be attained, since commercial cacao beans already contain a large proportion of fat, namely about 55 per cent. of the oven dry nib.

Another component which may be important from the manufacturer's point of view is lecithin, since it has been found that the addition of lecithin to warm chocolate increases its fluidity, and the proportion of fat necessary in the mixture may be reduced by as much as five per cent. Very little has been published on cacao lecithin, but Jäckle recorded a surprisingly high figure for lecithin in cacao butter. Since lecithin is one of the most important phosphorus compounds in plants, it is possible that botanical type and manurial treatment may affect the lecithin content of the bean.

Summary.

Biochemistry appears to occupy a key position in cacao research, and a fuller knowledge of the chemical components of the fresh bean and their changes during fermentation, drying, roasting,

and chocolate-making would co-ordinate the problems of the botanist, the planter, and the manufacturer. Many investigations have been carried out in factory laboratories, but frequently the previous history of the material was unknown, or only partly known. Similarly, researches which have been performed in cacao-producing countries have been handicapped by the fact that the final tests of roasting and chocolate manufacture were not always possible, and the experiments have thus been incomplete. Transport and storage of the cured bean must also be considered, since a large bean of good flavour and aroma is frequently associated with thinness of shell, hence its value might be considerably reduced by liability to breakage and to internal mould during transport.

To sum up, the chemist is faced with many biochemical problems in cacao production, and some of these have been studied intermittently during the past 50 years. Little or nothing is known about the composition of the fresh bean in relation to its genetic constitution, and in this field, close collaboration with the botanist might result in great mutual benefit. The botanist cannot breed for improved quality by selective propagation until he knows what quality means. In fermentation and drying, a great many isolated observations and trials have been made in the past, but comprehensive fundamental studies are lacking, such as might co-ordinate previous work in such a manner that the art of curing might be based on scientific principles. It is to the manufacturer that the cacao chemist must turn for advice and criticism, since his judgment of the planter's final product is the only basis on which quality can be evaluated. Whilst factory research has enabled manufacturers to overcome to some extent the natural variations which occur in the cacao beans of commerce, constancy of quality is recognised by them as the most important property in their raw materials. Researches of the nature described above must help towards this, and thus benefit both planter and manufacturer.